AFRICAN IRRIGATION OVERVIEW

MAIN REPORT

AFRICA

USAID

WATER MANAGEMENT SYNTHESIS II PROJECT

WMS REPORT 37

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MAIN REPORT

This study is an output of
Water Management Synthesis II Project
under support of
United States Agency for International Development
Contract AID/DAN-4127-C-00-2086-00

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December 1987

WMS Report 37

PREFACE

This study was conducted as part of the Water Management Synthesis II Project, a program funded and assisted by the United States Agency for International Development through the Consortium for International Development. Utah State University, Colorado State University and Cornell University serve as co-lead universities for the Project.

The key objective is to provide services in irrigated regions of the world for improving water management practices in the design and operation of existing and future irrigation projects and give guidance for USAID for selecting and implementing development options and investment strategies.

For more information about the Project and any of its services, contact the Water Management Synthesis II Project.

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ACKNOWLEDGEMENTS

This study depends heavily upon the published sources on African irrigation, supplemented by the authors' limited visits to France, Mali, Niger, and Zimbabwe (arranged through the Water Management Synthesis II Project) and fortuitous trips to Sudan, Nigeria, Somalia, Tanzania, Malawi, and Kenya. For published sources we are deeply indebted to the Irrigation Management Network of the Overseas Development Institute in London, and in particular to Mary Tiffen. The Land and Water Division in FAO made available extensive bibliographic documentation which was of great assistance. The two principal authors record their indebtedness also to various participants involved in preparing volumes one and two, some of whom have contributed their own chapters to this final volume. The size of the task and the consequent delays in completing the project have taxed the friendship and patience of our supervisors. Special thanks are owed to Worth Fitzgerald, Doug Merrey and Pat Fleuret of USAID, to Richard McConnen in Arizona, and to Jack Keller at Utah State University. The product is not, perhaps, what they anticipated; and any errors of fact or of interpretation remain our own responsibility. Finally, we express our deep appreciation to JoAnn Biery, Janet Chambers and Carolyn Fullmer for the tedious, behind-the-scenes effort required to bring this large volume to press.

J. Moris
D. Thom

ACRONYMS

ABD	- Action Blé-Diré, Mali; - Action Wheat-Diré, Mali.
ABN	- Autorité du Bassin du Niger; - Niger Basin Authority (NBA).
ACDI	- Agence Canadienne pour le Développement Internationale; - Canadian Agency for International Development.
ACSAD	- Arab Center for the Studies of Arid Zones and Dry Lands.
ADRAO	- Association pour le Développement de la Riziculture en Afrique de l'Ouest; - West African Rice Development Association (WARDA).
AGCD	- Administration Générale de la Coopération au Développement, Belgique; - Administration for Development Cooperation, Belgium.
AID	- Agency for International Development, Washington, D.C.
ARS	- Action Riz, Sorgho-Gao, Mali; - Action Rice, Sorghum-Gao, Mali.
ARSO	- Autorité pour la Région du Sud-Ouest, Côte d'Ivoire; - Southwest Regional Authority, Ivory Coast.
AVV	- Autorité des Aménagements de Vallées des Volta; - Volta River Authority.
BAD	- Banque Africaine de Développement; - African Development Bank.
BADEA	- Banque Arabe pour le Développement Economique de l'Afrique; - Arab Bank for African Economic Development.
BAN	- Bulletin, de l'Afrique Noire; - Black African Bulletin.
BCEAO	- Banque Centrale des Etats de l'Afrique de l'Ouest; - Central Bank of West African States.
BCOM	- Bureau Central d'Etudes pour les Equipements d'Outre Mer; - Central Office for the Study of Overseas Equipment.
BDPA	- Bureau pour le Développement de la Production Agricole, Paris, France; - Office of Agricultural Production and Development, Paris France.

BEAC	- Banque des Etats de l'Afrique Centrale; - Bank of Central African States.
BEDI	- Bureau d'Etudes pour le Développement Integré, Cameroun; - Office for the Study of Integrated Development, Cameroon.
BEI	- Banque Européenne d'Investissement; - European Investment Bank.
BID	- Banque Islamique de Développement; - Islamic Development Bank.
BIRD	- Banque Internationale pour la Reconstruction et le Développement; - International Bank for Reconstruction and Development (IBRD).
BNETD	- Bureau Nationale d'Etudes Techniques de Développement (Côte d'Ivoire); - National Office for Technical Development Studies (Ivory Coast).
BRALUP	- Bureau of Resource Assessment and Land Use Planning, Tanzania.
CBLT	- Commission du Bassin du Lac Tchad; - Lake Chad Basin Committee.
CCCE	- Caisse Centrale de Coopération Economique
CDC	- Commonwealth Development Corporation.
CEA	- Commission Economique pour l'Afrique; - Economic Commission for Africa (ECA).
CEAO	- Communauté Economique de l'Afrique de l'Ouest; - Economic Community of West Africa.
CEDEAO	- Communauté Economique des Etats de l'Afrique de l'Ouest; - Economic Community of West African States (ECOWAS).
CEE	- Communauté Economique Européenne - European Economic Community (EEC).
CEEMAT	- Centre d'Etudes d'enseignement de la Machinisme Agricole Tropicale; - Center for the Study and Teaching of Tropical Agricultural Machinery.
CEJC	- Centre d'Etudes Juridiques Comparatives, Paris, France; - Study Center for Comparative Law, Paris, France.
CENECA	- Centre National de Expositions e Concours Agricole; - National Center for Expositions and Agriculture Competitions.

CFDT - Compagnie Française pour le Développement des Fibres Textiles;
- French Company for the Development of Textile Fibers.

CFN - Commission du Fleuve Niger;
- Niger River Commission.

CIDAT - Centre d'Informatique Appliquée au Développement et à l'Agriculture Tropical;
- Center for Applied Inquiry into Development and Tropical Agriculture.

CIDR - Compagnie Internationale de Développement Rural;
- International Company for Rural Development.

CIEH - Centre Inter-Africain d'Etudes Hydraulique;
- Inter-African Center for Hydraulic Studies.

CILLS - Comité Inter-Etats de Lutte Contre la Sécheresse du Sahel;
- Interstate Committee for the Struggle Against Sahelian Drought.

CIPEA - Centre International pour l'Elevage en Afrique, Addis-Abeba;
- International Livestock Center for Africa, Addis-Ababa, (ILCA).

CMDT - Compagnie Malienne de Développement des Textiles;
- Malian Company for Textile Development.

CNCA - Caisse Nationale de Credit Agricole.

CNEAT - Centre National d'Etudes Agronomie Tropicale;
- National Center for the Study of Tropical Agronomy.

CNRA - Comité National de la Recherche Agronomique, Mali;
- National Committee for Agronomie Research, Mali.

CNRS - Centre National de Recherche Scientifique, Paris, France;
- National Center for Scientific Research, Paris, France.

CWS - Church World Service.

DGRST - Delegation Generale à la Recherche Scientifique et Technique, Paris, France;
- Delegation for Scientific and Technical Research, Paris, France.

EDIAFRIC - Editions Africaines, Paris, France;
- African Editions, Paris, France.

EDF - Electricité de France, Paris, France;
- Electricity of France, Paris, France.

EPHE - Ecole pour les Haute Etudes;
- School for Advanced Studies.

ENSA - Ecole Nationale Supérieure Agronomie;
- National School of Agronomy.

ENSAT - Ecole Supérieure d'Agronomie Tropicale;
- School of Tropical Agronomy.

FAC - Fonds d'Aide et Coopération, Paris, France;
- Fund for Aid and Cooperation, Paris, France.

FAD - Fonds Africain de Développement;
- African Development Fund.

FADES - Fonds Arabe pour le Développement Economique et Social;
- Arab Fund for Economic and Social Development.

FED - Fonds Européen de Développement, Paris, France;
- European Development Fund, Paris, France.

FEDES - Fonds de Développement Economique et Social;
- Economic and Social Development Fund.

FIDA - Fonds International de Développement Agricole;
- International Agricultural Development Fund.

FIDOM - Fonds d'Investissement des Départements d'Outre Mer;
- Overseas Departments Investment Fund.

GERCA - Groupement d'Etudes Rurales en Casamance, Senegal;
- Study Group for Rural Studies of Casamance, Senegal.

GERDAT - Groupement d'Etudes et de Recherches pour le Développement de l'Agronomie Tropicale, Paris, France;
- Study Group for Research and Development of Tropical Agronomy, Paris, France.

GERSAR - Groupement d'Etudes et de Réalisation des Sociétiés d'Aménagements Régional;
- Study Group for the Implementation of Regional Management Societies.

GMP - Groupe Moto-pump;
- Motor Pump Group.

GRDT - Groupe de Recherche et de Réalisations pour le Développement Rural dans le Tiers Monde;
- Research Group for Rural Development in the Third World.

HMSO - Her Majestys' Stationery Office.

IAI - International African Institute.

IBRD - International Bank for Reconstruction and Development (World Bank).

ICRISAT - International Crops Research Institute for the Semi-Arid Tropics.

IEDES - Institut d'Etudes du Développement Economique and Sociale;
- Institute for the Study of Economic and Social Development.

IER - Institut d'Econcmie Rural, Mali;
- Institute for Rural Economy, Mali.

IFAN - Institut Fondamental d'Afrique Noire, Senegal;
- Fundamental Institute for Black Africa, Senegal.

IGN - Institut Géographique National, France;
- National Geographic Institute, France.

IITA - International Institute for Tropical Agriculture, Ibandan;
- Institut International pour l'Agriculture Tropical, Ibandan.

ILACO - International Land Development Consultants Ltd.; Arnhem, Netherlands.

IMF - International Monetary Fund.

INA - Institut National Agronomique;
- National Institute of Agronomy.

INEAC - Institut National pour l'Etude Agronomique du Congo (Belge);
- National Institute for the Study of Agronomy in the Congo (Belgian).

INRA - Institute National de la Recherche Agronomique, France;
- National Institute for Agronomic Research, France.

INRAN - Institut National de Recherche Agronomique du Niger;
- National Agronomic Research Institute of Niger.

INSEE - Institut National de la Statistique et des Etudes Economiques;
- National Institute of Statistics and Economic Studies.

IRAM - Institut de Recherches et d'Applications de Methodes de Développement;
- Institute for Research and Application of Development Methods.

IRAT - Institut de Recherches Agronomique Tropicales et de Culture Vivrières;
- Research Institute for Tropical Agronomy and Food Crops.

IRRI - International Rice Research Institute, Philippines;
- Institut International de Recherches Rizicoles. Philippines.

KDF - Fonds Koweitien de Développement;
- Kuwaiti Development Fund.

LWR - Lutheran World Relief.

MAT - Machinisome Agricole Tropical.

NBA - Niger Basin Authority.

NIB - National Irrigation Board, Kenya.

NGO - Non-Governmental Organization.

OAA - Organisation des Nations Unies pour l'Alimentation et l'Agriculture;
- Food and Agriculture Organization (FAO).

OCAM - Organisation Commune Africaine et Malagache;
- Community Organization of Africa and Malagache.

OCDE - Organisation de Coopération de Développement Economique;
- Orginization for Economic Cooperation and Development (OECD).

ODA - Overseas Development Administration.

ODI - Overseas Development Institute, London.

OECD - Organization for Economic Cooperation and Development.

OMVG - Organisation pour la Mise en Valeur du Fleuve Gambie;
- Organization for the Development of the Gambia River.

OMVS - Organisation pour la Mise en Valeur du Fleuve Sénégal;
- Organization for the Development of the Senegal River.

ON - Office du Niger, Mali.

ONBI - Office National des Barrages et d'Irrigation, Bourkina Fasso;
- National Office for Dams and Irrigation, Burkina Faso.

ONAHA - Office National des Aménagements Hydro-Agricole, Niger;
- National Office for Hydro-Agricultural Development, Niger.

ONRD - Office Nationale de la Recherche et du Développement;
- National Research and Development Office (Belgium).

ORM - Opération Riz-Mopti, Mali;
- Operation Rice-Mopti, Mali.

ORS - Opératon Riz-Ségou, Mali;
- Operation Rice-Segou, Mali.

ORSTOM - Office de Recherche Scientifique et Technique d'outre Mer, Paris, France;
- Office of Overseas Scientific and Technical Research, Paris, France.

OTER - Office des Travaux d'Equipment Rural, Mali;
- Office for Rural Equipment Works, Mali.

OUA - Organisation de l'Unité Africaine;
- Organization of African Unity (OAV).

OVSTM - Opération Vallée du Sénégal, la Térékolé et du Lac Maque, Mali;
- Operation of the Senegal Valley, Térékolé and Lake Maqui, Mali.

OZL - Opération Zone Lacustre, Mali;
- Operation Lacustrine Zone, Mali.

PIV - Périmètre Irrigué Villageois;
- Village Irrigated Perimeters.

PIRT - Projet Inventaire des Ressources Terrestres, Mali;
- Land Resources Inventory Project, Mali.

PNUD - Programme des Nations-unis pour Développement;
- United Nations Development Program (UNDP).

PVO - Private Volunteer Organization.

RAMS - Rural Assessment and Manpower Surveys.

REDSO - Regional Economic Development and Services Office (AID), Abdijan, Ivory Coast. Nairobi, Kenya.

SAED - Société d'Aménagement et des Etudes de Développement;
- Company for Study and Execution of Development, France.

SAED - Société d'Aménagement et d'Exploitation des Terres du Delta;
- Delta Canal Development Corporation, Senegal.

SATEC - Société d'Aide Technique et de Coopération;
- Company for Technical Aid and Cooperation.

SCET - Société Centrale pour Equipment du Territoire International;
- Central Company for Equipment of International Territories.

SCIP - South Chad Irrigation Project.

SDPT - Sahel Development Planning Team, Mali.

SEAE - Secretariat d'Etat pour les Affaires Etrangères;
- Secretary of State for Foreign Affairs.

SEDAGRI - Société d'Etudes et de Développement Agricole;
- Company for the Study of Agricultural Development.

SEDES - Société d'Etudes pour le Développement Economique et Social, Paris, France;
- Company for the Study of Social and Economic Development, Paris, France.

SEMRY - Société d'Expansion et Modernisation de la Riziculture de Yagoua, Cameroun.
- Company for the Expansion and Modernization of Rice Cultivation at Yagoua, Cameroon.

SODELAC - Société de Développement du Lac (Tchad);
- Company for the Development of Lake Chad.

SODEVA - Société de Developpement et de Vulgarisation Agricole, Sénégal;
- Society for Agricultural Development and Extension, Senegal.

SOGETHA - Société Générale des Techniques Hydro-Agricoles, France;
- General Company for Hydro-Agricultural Techniques, France.

SOGREAH - Société Grenobloise d'Etudes et d'Application Hydrauliques, Grenoble, France;
- Grenoble Company for the Study and Application of Hydrology, Grenoble, France.

SONADER - Société Nationale pour le Développement Rurale, Mauritanie;
- National Company for Rural Development, Mauritania.

UNCC - Union Nationale de Crédit et de Coops, Niger;
- National Union for Credit and Coops, Niger.

UNDP - United Nations Development Program.

UNEP - United Nations Environment Program.

USAID/ - United States Agency for International Development.
WARDA - West African Rice Development Association.

WMO - World Meteorological Organization.

WMS-II - Water Management Synthesis-II, an AID funded project through the Bureau of Science and Technology.

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CHAPTER ONE

INTRODUCTION

The need for irrigation is commonly judged in relation to a country's climate: the adoption of irrigation being seen as a necessary (or "privileged") technological response to permit crop production under conditions of increasing aridity. Irrigation potential is, on the other hand, determined by the availability of water near suitable soils. The two need not coincide. A major observation about tropical Africa is that here they often do not; the nations with the greatest potential for future irrigation development are not necessarily the countries with the greatest present needs. Where irrigation need and potential coincide--as along the Senegal and Niger rivers in West Africa or the Nile in the Sudan--a substantial development of irrigated agriculture has already occurred.

Based on crude estimates of food self-sufficiency in relation to climate, a recent FAO study (1986) identifies eight sub-Saharan countries where further development of irrigation should take priority: Senegal, Mauritania, Mali, Burkina Faso, Niger, Somalia, Kenya and Botswana (to which we would add Chad). The criterion employed to derive this listing was that more than 85 percent of a country's area would have less than a 200 day growing period--which explains the inclusion of Kenya, though the large semiarid northeastern zone is only thinly populated. In dry periods, such as in 1973-74 and again 1983-84, Sudan, Ethiopia and Tanzania might be added. The proportion of the population living in the eight most affected countries is roughly 14 percent of the sub-Saharan African total (FAO, 1986). If, however, we add the countries where drought is a persistent concern, this percentage would probably double. Regional droughts have afflicted the northern sections of all the countries bordering upon the Sahel zone of West Africa, with Nigeria and Ghana providing particularly good examples (Shepherd, 1981). They are also significant in the horn of Africa and in the southern African countries of Angola, Zimbabwe, Mozambique, and in parts of Madagascar. Even in other countries with ample total water resources there are localized dry zones requiring irrigation, e.g., northern Cameroon or southern Malawi. Thus, active consideration of irrigation as a policy option occurs in many African countries, typically reaching a peak intensity during and after major droughts.

Three objectives predominate in national discussions of irrigation policy within sub-Saharan Africa: (1) alleviating the impacts of drought; (2) stabilizing internal food supplies; and (3) saving the hard currency which otherwise would be spent on food imports. In addition, proponents of irrigation often add the creation of rural employment as a subsidiary goal. When coupled with the notion that irrigation is "modern" and technologically "efficient," these objectives have often been sufficient to insure a privileged position for irrigation projects within national programs for agricultural development--particularly within the Sahel and the Sudan (Africa's largest single country). This association is significant, since irrigation in the form typically adopted by African governments tends to be extremely expensive. The cost-effectiveness of irrigation investments in an African setting will emerge as a key issue at many points throughout this report. Here we would point out simply that a concern over the economics of irrigation has arisen mainly from external donors, who have questioned the appropriateness of irrigation investments in poor countries at early stages of commercialization (Carruthers, 1983). To African policy makers irrigation retains the aura of being the best technology for insuring food sufficiency and for stabilizing rural development within the continent's large, semiarid zone.

Volume I of this study presents an overview of these issues, oriented toward broad policy concerns. In this volume we attempt to show that the views of donors and/or recipient governments are both oversimplified. Africa has greater need for irrigation than most donors will admit, but the achievements to date have been disappointing and the constraints are severe. If African countries are determined to continue subsidizing their irrigation projects, at least they should learn from the mistakes made in the first and second generation projects of the colonial and immediate post-independence periods.[1]

Types of African Irrigation

Some of the confusion which arises in trying to weigh the arguments for and against African irrigation is a consequence of conflicting and contradictory definitions. Donors interested in assisting Africa come with their own national traditions which define what irrigation is. They are likely to forget that the larger systems in Africa were designed by colonial engineers to meet local needs, which over time have evolved into distinctive systems rather different from those found in developed nations. Also, Africa's indigenous small-scale systems are an amalgam of ancient, mid-eastern or north African technology and farmers' own adjustments to a tropical environment. Despite the fact these spontaneously evolved technologies feed more people than do the introduced systems, they were not taken seriously by engineers because of their apparently crude construction techniques.

The types of irrigation found in Africa today can be best outlined by a brief reference to the contrasting descriptors already used in this chapter when introducing our topic. The key distinctions are:

irrigation versus drainage
farmers versus operators

[1]Among published sources dealing with general issues or providing comparative documentation on African irrigation are Steinberg, (1983); Carruthers, (1983); Blackie, (1984); Adams and Grove, (1984); Biswas (1986), Conac et al., (1985), and FAO (1986, 1987) and Rangely (1985).

total versus supplemental
full control versus partial
large-scale versus small-scale
formal versus nonformal
introduced versus traditional

Textbook definitions of irrigation emphasize it consists of technologies designed to supply plants with water, whereas drainage consists of measures intended to remove excess water. We prefer to say that irrigation exists when by human intervention plants are enabled to meet their moisture requirements. However water is applied, retained, or removed, the key fact is that at least some increase of control over natural conditions is achieved. By highlighting the agronomic objective of regulating the moisture available to plants, we are intentionally blurring the usual distinction drawn between "irrigation" and "drainage." Under tropical conditions, both are usually necessary and interrelated components in the operation of actual systems (see the discussion of drainage in Chapter Four). Traditional forms of irrigation in Africa's wetter lands usually incorporate both elements, with the farmer at first trying to drain waterlogged fields and later retaining or adding water to extend the moisture regime.

The word "farmer" is also a source of confusion. In point of fact, the person supplying the water to plants is an operator who may or may not own the land being cultivated. Often, in Africa's larger schemes, those doing irrigation are tenants, not farmers: they hold their rights to land and water under a legal arrangement with a larger organization, the irrigation scheme. Schemes vary in the degree of autonomy which they permit to their tenants. Irrigation projects designed by outsiders frequently assume that people will show the interest and motivation one would expect from farmers, when in reality these conditions are not found within actual schemes. This has been an important reason for the low performance often seen on Africa's formal irrigation schemes (a topic addressed in chapters six and seven).

While all forms of irrigation are based on a desire to increase the water available when needed, the amounts of water required and the degrees of control achieved differ. "Total irrigation" describes regimes where the operator supplies most of the plants' water needs, whereas "supplemental irrigation" refers to situations where rainfed cultivation is augmented by the irrigator. The importance of supplemental irrigation in the Tropics arises because potential evaporation is so high, greatly increasing plants' water stress, and because water retention is very poor in some situations (e.g. in sandy soils). In much of Africa, engineering solutions to increase water availability have been concentrated on "total irrigation" even in those environments where there is substantial natural rainfall (e.g., Kenya's Mwea Scheme at the foot of Mt. Kenya). However, in parts of the Sahel where farmers' indigenous techniques utilized recessional (décrue) cultivation following an annual flood, French engineers devised polders and dikes to assist in retaining the river's water. Since such systems do not control the ultimate supply (which may fail in dry years), they have been termed "partial control" systems in contrast to "full control" irrigation.

While Africa's large projects such as Mali's Office du Niger or Sudan's Gezira Scheme are large by most standards (the combined Gezira-Managil schemes cover approximately two million acres, making them one of the largest irrigation complexes in the world), Africa's irrigation projects are as a rule considerably smaller than some of those found in South Asia. FAO has proposed four size categories for describing African systems:[1]

- very large-scale schemes (over 10,000 ha);
- large-scale schemes (from 1,000 to 10,000 ha);
- medium-scale schemes (from 100 to 1,000 ha); and
- small-scale schemes (from 1 to 100 ha).

To these we would add "micro-irrigation" (less than 1 ha) for certain very small traditional systems, such as the calabash watered gardens of Mali's Bandiagara plateau (Moris, Thom and Norman, 1984). The cutoff points in this categorization imply that size distinctions are more crucial at the lower end of the continuum. This seems to be the case in real systems: small- and medium-scale projects appear to require proportionately more management and technical attention than do equivalent sized units within large-scale schemes, where standardized water control devices are usually encountered throughout the system.

Because the adoption of irrigation has tended to be in response to governmental initiatives--with the notable exceptions of Sudan's private pump schemes and some estate producers in East and Southern Africa--water engineers may be requested to design and assist very small projects. In developed countries, a pump system serving, say, 40 hectares would probably fall within a single farm and might be arranged by the owner without external assistance. In Africa, to the contrary, where farmers rely on hand cultivation, a similar project would involve perhaps some 30-50 separate households. The sites being irrigated often exhibit a high degree of local variability in soils and terrain. The agronomic and hydrological problems they pose can be just as demanding of technical skill as would a much larger project.

The absence of medium-sized, commercial operators means that in many African countries, irrigation systems are polarized between a few, larger-scale government schemes and a number of very small independent irrigators. The latter practice various "traditional" techniques, employed with hardly any outside assistance. These days they are incorporating some modern (or "introduced") equipment, notably small pumps, but their whole mode of financing and operation is very different from that employed on the large-scale, official schemes. The designation of "scheme" here has genuine significance. Such projects are designed from outside, externally financed (in many instances), and usually employ

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[1]FAO (1986) "State of Irrigation--Facts and Figures," Background Paper for the Consultation on Irrigation in Africa (Lomé, Togo, 21-25 April, 1986), p. 14.

salaried staff. As a consequence, governmentally initiated projects tend to be larger, to have a formal organizational structure, and to depend upon introduced irrigation technologies. The project documentation which one finds in donor's files tends to represent these official schemes, which are analyzed in chapters three, four, eight and nine of this report.

It is harder to describe what happens in the small-scale, non-formal systems devised by African farmers themselves. Farmers' own efforts to control water are usually on a very small scale. The purchase of a single pump may represent the culmination of a major effort among subsistence farmers. Production objectives are more likely to be oriented toward securing farmers' own food supplies. Without mechanization, the production system resembles horticulture as much as it does arable field farming, down to the extreme of one meter square "boxes" into which calabash-carried water is poured. Frequently, indigenous technology was adaptive rather than manipulative (Richards, 1985). In the décrue cultivation widely seen along the Senegal and Niger Rivers (sometimes called "recessional irrigation"), farmers would plant crops in sequence down the slope as the river's flood retreated. Peasants in East and Central Africa learned to plant crops on raised beds in the valley bottoms, adding tie ridges and in-furrow checks to extend the moisture regime. At this extreme, few expatriate engineers would consider such water management practices as "irrigation." Nonetheless, they achieve the same objective as the much more expensive, imported technologies used on official schemes.

Awareness of water as a common resource shared between various production systems is fairly recent in African planning. The tremendous differences between the two main types of irrigation (as just outlined) has inhibited any sharing of experience or assistance between them. It has proven very difficult for government agencies and external donors to work with Africa's small-scale systems, though there are a few instances of partial success (in Senegal and Tanzania). The extreme duality which characterizes the irrigation sector in most sub-Saharan countries is unfortunate. It makes it unlikely that successful smaller projects will evolve into medium-scale operations which might combine high farmer involvement with economies of scale in water management.

Perhaps this explains why there are so few adequate reviews of the sector-wide experience with irrigation in Africa contexts. Instead, each specialty has developed its own classification schemes and notions about how irrigation should be practiced. Engineers working in Africa tend to categorize irrigation technologies by their water supply and conveyance mechanisms: recognizing dams, run-of-the-river gravity systems, pumps, and polders. Irrigation specialists outside Africa distinguish systems instead by their water application devices: categorizing them into sprinkler, border, basin, furrow, trickle, or water spreading types. We prefer a recent, combined classification proposed by Jack Keller (Table 1). It highlights several features of particular importance in Africa, though it does differ from the FAO classifications commonly used in the continent.

TABLE 1

ESTIMATED PERFORMANCE OF VARIOUS ON-FARM IRRIGATION SYSTEMS WITH EQUAL WATER IN DEVELOPING COUNTRIES

(A=Excellent, B=Good, C=Fair, D=Poor, F=Fail, X=Null set, and U=Unknown)

ENERGY INPUTS and Types of Conveyance and Application Systems	IRRIGATION SYSTEM RELATIVE SIZE, OWNERSHIP AND MANAGEMENT CAPACITY							
	IRRIGATION SYSTEMS SERVING UNIFIED FARMS [1]				IRRIGATION SYSTEMS SERVING MULTIPLE FARMS [2]			
	Individual/Collective		Parastatal		Individual/Community		Public Owner	
	Traditional Mgt.	Modern Mgt.	Typical Mgt.	Modern Mgt.	Traditional Mgt.	Modern Mgt.	Typical Mgt.	Modern Mgt.
GRAVITY FLOW [3]								
Earth Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Lined Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Pipe to Surface								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Piped to Pressurized								
Hand - Local	—/—	—/—	—	—	—/—	—/—	—	—
Hand - Total	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Local	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Total	—/—	—/—	—	—	—/—	—/—	—	—
ELECTRIC PUMPED								
Earth Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Lined Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Pipe to Surface								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Piped to Pressurized								
Hand - Local	—/—	—/—	—	—	—/—	—/—	—	—
Hand - Total	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Local	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Total	—/—	—/—	—	—	—/—	—/—	—	—
DIESEL PUMPED								
Earth Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Lined Channel								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Pipe to Surface								
Paddy (Rice)	—/—	—/—	—	—	—/—	—/—	—	—
Upland Traditional	—/—	—/—	—	—	—/—	—/—	—	—
Upland Modern	—/—	—/—	—	—	—/—	—/—	—	—
Piped to Pressurized								
Hand - Local	—/—	—/—	—	—	—/—	—/—	—	—
Hand - Total	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Local	—/—	—/—	—	—	—/—	—/—	—	—
Automatic - Total	—/—	—/—	—	—	—/—	—/—	—	—

[1] Assumes that farm and system ownership and management are the same. (Scale of the irrigation system and farming units are the same.)
[2] Assumes that each of the multiple farms are owned and managed by private individuals. (Large-scale irrigation systems on small fields.)
[3] Where reliable pumping is provided at a large public project level the on-farm systems will behave as "gravity flow" systems.

A moment's reflection will indicate why it is not practical to impose a single, unified typology upon African irrigation systems. Any categorization carries with it implicit suppositions about the universe being classified--a prime reason why classification schemes derived elsewhere may require modification when used in Africa. Even in the USA, civil engineers use the Bureau of Reclamation's "unified" soil taxonomy when evaluating construction costs, whereas agronomist's employ USDA's soil taxonomy when evaluating agricultural potential. The participants to this study contributed two classification schemes, one by Vincent (in Chapter Two) oriented towards hydrology, and the other by Humpal (in Chapter Five) towards agronomy.

In regard to irrigation technologies, while polders and water spreading are uncommon within the U.S.A. (and so receive scant attention from most U.S. authorities), they are significant in Africa. Again, because supply difficulties bulk large in decision-making about African irrigation systems, those working on the continent tend to make the nature of the supply a central feature of their classification systems. Furthermore, while modern systems are easily separated according to the type of technology they employ, traditional systems are not. It is often more productive to review traditional irrigation in relation to the site characteristics where it has evolved (e.g., oases, swamps, depressions, flood recession, market gardens, and mountain furrows).

The diversity of classifications and types necessary for describing African irrigation becomes more comprehensible if one studies Figure 1 derived from Okigbo's important (1984) FAO study on the stabilization of shifting cultivation in Africa. What this diagram makes clear is that irrigated farming cross-cuts environmental zones along a broad continuum, from moist climates with only 1-2 dry months to very dry ones with perhaps only 1 humid month in each year. Much of the writing on African irrigation is phrased as if the main opportunities are concentrated in semiarid countries like Somalia or Mauritania. As we shall see when reviewing the arguments for and against African irrigation, this is most certainly not the case. The "limits of aridity" are different for animal producers than for crop producers, and they differ from crop to crop. In addition, the high potential evapotranspiration experienced in the tropics means that while a city like Nairobi has roughly the same rainfall as London, Nairobi appears (to tourists and farmers alike) a much drier place. Coffee estates outside Nairobi employ supplemental irrigation routinely, as do also tea growers in parts of highland Malawi. Necessarily, the potential for obtaining higher crop yields by irrigating exists over a wide spectrum of African environments, even though proven technologies to accomplish this objective are still under development.

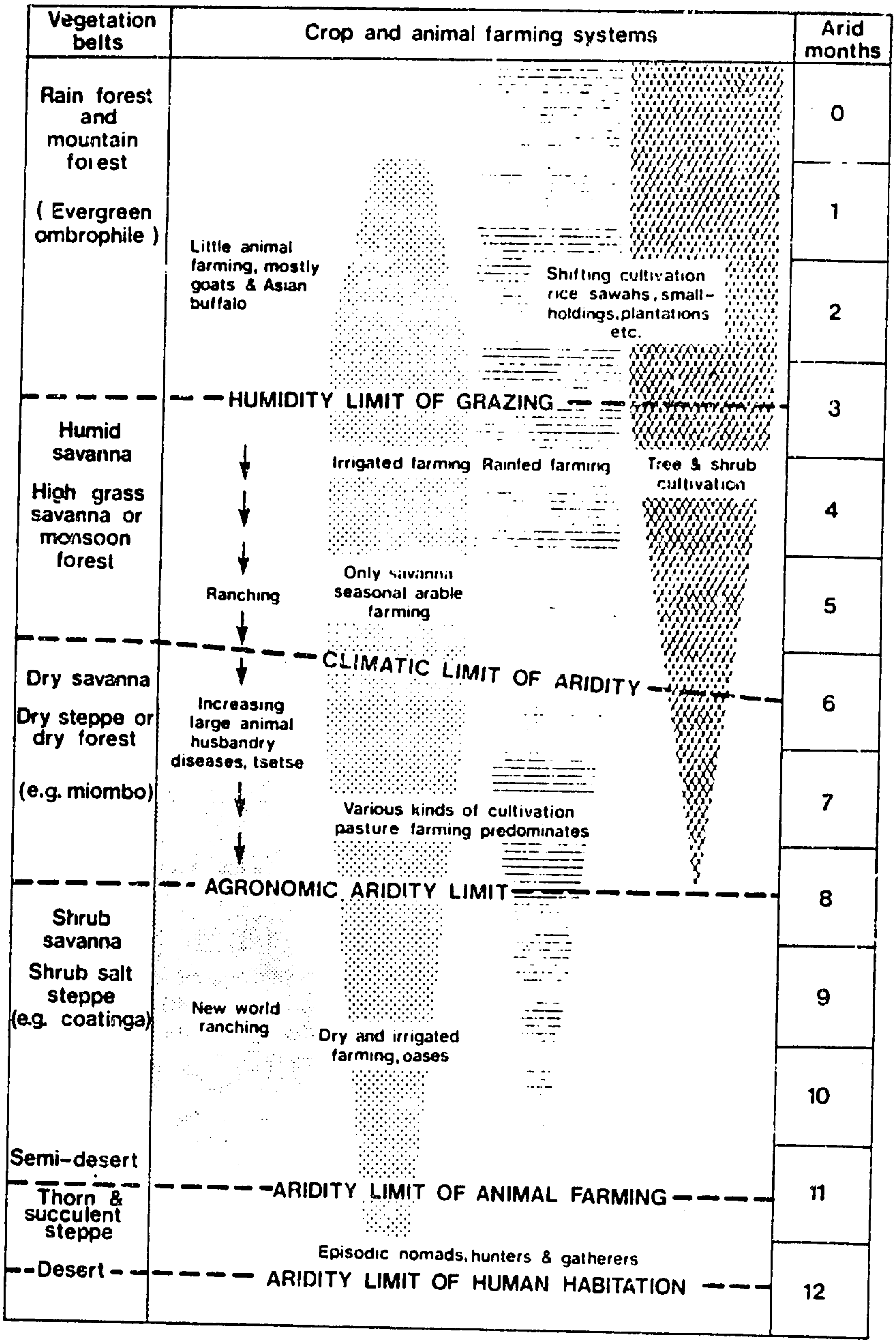
The Case for African Irrigation Development

The case for increasing irrigation development within tropical Africa rests upon a number of interrelated arguments:

- The buildup of human populations within Africa's drier lands,

FIGURE 1

FARMING SYSTEMS IN RELATION TO ARIDITY



Source: Bede Okigbo, "Improved Permanent Production Systems as an Alternative to Shifting Intermittent Cultivation," In: FAO, Improved Production Systems as an Alternative to Shifting Cultivation. Rome: FAO, 1984.

exceeding the carrying capacity of rainfed farming;

- The potential role of irrigation in relieving the long dry season, which is characteristic of much of tropical Africa;

- The critical importance of supplemental irrigation to insure adequate returns from key export crops (particularly coffee);

- The large potential impact of supplemental irrigation within "rainfed" cropping systems;

- The possibility of employing irrigation to relieve nutritional constraints in African livestock production;

- Availability of special environments particularly suited to irrigation production; and

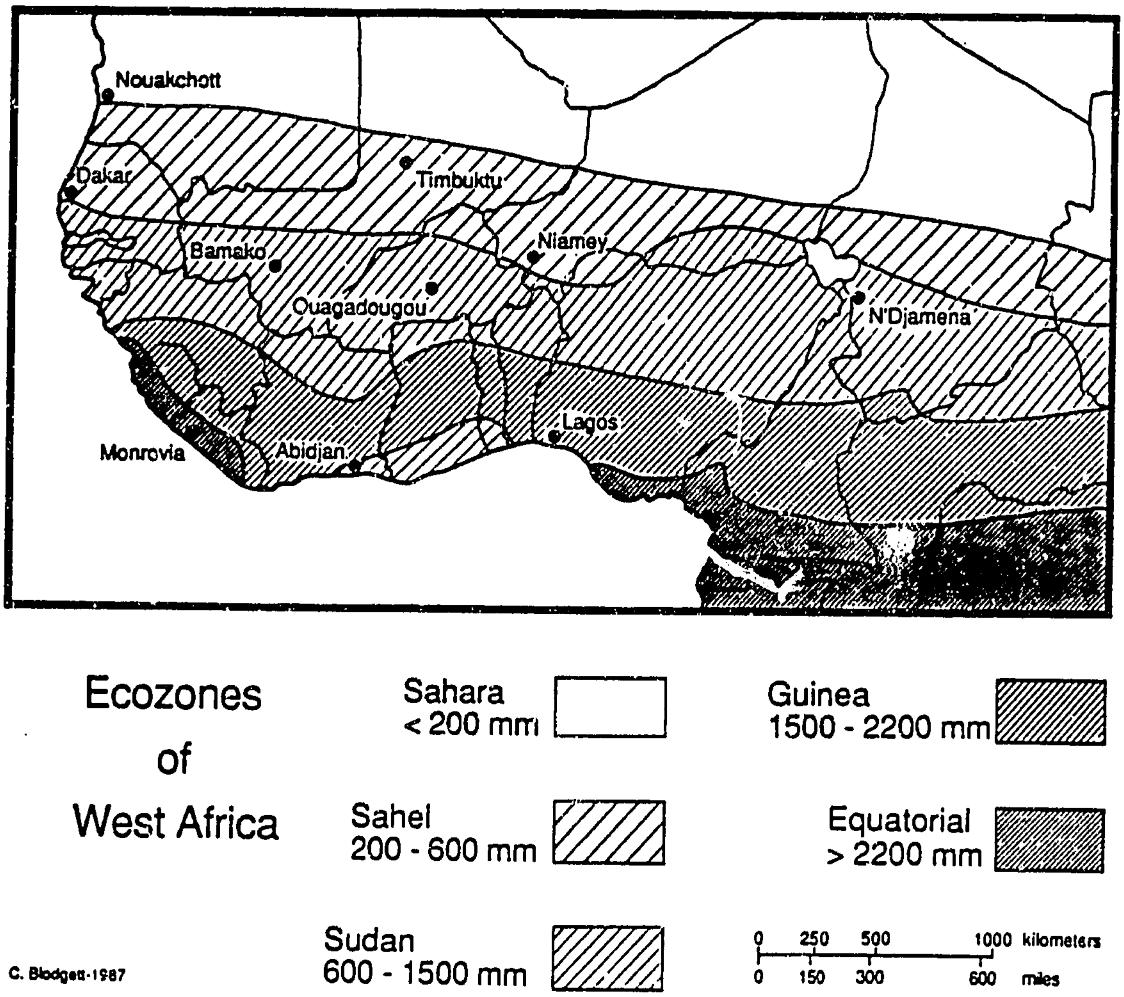
- Long-run prospects for tapping Africa's large hydropower potential as the source of water and energy for irrigated agriculture.

Relieving Drought

We begin with the semiarid countries which have little choice but to irrigate if they wish to support their present populations. Basically, these consist of the Sahel countries of West Africa, the drier portions of northeast Africa and the borderlands of the Kalahari Desert in southern Africa. From Mauritania and Senegal eastward to the Ethiopian plateau, all the countries along the southern fringes of the Sahara straddle the transition zone from true desert in the north to savanna-like parklands (the "sudanic zone") in the south. This is what is termed the "Sahel," being a zone demarcated roughly by the rainfall isohyets of 100 mm in the north and between 500 and 600 mm in the south (Figure 2). A similar but less geographically uniform gradation occurs running along a north-south axis on the eastern edge of the Rift Valley highlands (incorporating large portions of Ethiopia, Somalia and Kenya). In both zones the concentration of human populations already exceed what can be supported from rainfed agriculture--a food deficit which emerges most sharply in the drier years, such as occurred in 1973-74 and again in 1983-84. Another similarity is the prominence of transhumant livestock production as the traditional basis of economic activities on rangelands with less than 400 mm of rainfall per annum.

It has often been alleged that human misuse of the environment in such settings is the underlying cause of the misfortunes people experience in dry years (Katz and Glantz, 1977), with the blame apportioned among several interrelated trends. Overstocking of fragile rangelands during the higher rainfall years can lead to a "tragedy of the commons" scenario in the drier periods. Improvements in health services may have lowered death rates within human populations, so that there are more people to feed (a larger proportion of which are young children). Within the wetter half of the Sahel zone, high risk arable farming has

FIGURE 2


Nouakchott
Dakar
Timbuktu
Bamako
Niamey
Ouagadougou
N'Djamena
Lagos
Monrovia
Abidjan
Ecozones
of
West Africa
Sahara
< 200 mm
Sahel
200 - 600 mm
Sudan
600 - 1500 mm
Guinea
1500 - 2200 mm
Equatorial
> 2200 mm
0 250 500 1000 kilometers
0 150 300 600 miles
C. Blodgett-1987

become established. Plow farming accentuates land degradation in bad years, leaving entire communities to rely upon governmentally provided famine relief. From this perspective, donor-sponsored famine relief projects--whether of a short-term, food relief nature or with a longer term agricultural assistance bias--only exacerbate the fundamental problem of land misuse within already overpopulated lands. It is also sometimes claimed that there is no empirical evidence of an actual long-run decline in rainfall. A series of two or three dry years in each decade is a "normal" feature which local systems have often encountered in the past. What has changed is the decreasing effectiveness of accommodative mechanisms, triggered by an unprecedented buildup of human and animal populations. That is indeed a powerful line of argument. Many technical experts accept it as an accurate diagnosis of the reasons for emergent food deficits in the semiarid parts of Africa.[1]

The contrary view accepted by many African governments runs as follows. First, while seasonal and local droughts of 1973-74 and again 1983-84 were continent-wide, they far exceeded what might be attributed to human causation. For example, the 1983 and 1984 low water levels on the Niger River matched the hundred year minima; and again, satellite imagery documented decreased vegetative growth over the whole continent--even in densely forested areas far from human occupation (Tucker, et al., 1985). Second, there has been a real expansion of the Sahara southward, and archaeological excavations reveal similar fluctuations at several periods in the distant past. Third, the shortfall in food production occurs in part because people must grow export crops (like cotton or peanuts) in places where otherwise they once grew drought-resistant indigenous grains (millet and sorghum). The buildup of export crop production within the Sahel before the 1973-74 drought took valuable forage reserves out of the pastoral system at the same time as it left people with insufficient food once the dry years returned (Franke and Chasin, 1980). A fourth consideration in West Africa at least is that areas of present population concentration reflect the incidence of tsetse flies (carrying human and animal forms of sleeping sickness) and other flies which carry the dreaded "river blindness" (onchocerciasis). Whole sections of the Sudanic zone in West Africa have been abandoned when the outbreaks of onchocerciasis became too severe. Instead, the medieval African kingdoms were actually located farther north, either in the Sahel or on its borders. With certain exceptions (such as Nigeria, which is densely settled), much of the West African forest zone is still thinly populated; the present concentrations of people farther north thus reflect an ancient pattern (Figure 2).

Whichever view one espouses, the success of irrigated agriculture must be seen as a key ingredient essential for the long-run development of Africa's semiarid lands. Even the most convinced proponents of the overpopulation thesis will admit that the atypical occurrence of major rivers and their associated inland deltas within the dry zones represents

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[1]For a popular presentation of this viewpoint, see the booklet Famine, a Man-Made Disaster? by the Independent Commission on International Humanitarian Issues (1985).

a significant opportunity. Rivers like the Nile, the Niger, the Senegal and the Juba make irrigation technically feasible over a large area which is already populated and where rainfall alone cannot support reliable crop production. To African leaders within the affected countries, further attention to irrigation seems unavoidable. The traditional systems for migratory pastoralism which once constituted the principal alternative are breaking down; irrigated production seems the main technical option which might stabilize food supplies within the region. This viewpoint is taken for granted within the Sudan, already heavily dependent on Africa's largest irrigation sector. It also underlies Somalia's intense desire to develop irrigation along the Juba, and is the basis of much of the planning conducted within the CILSS/Club du Sahel organization (established in West Africa after the 1973-74 drought).

To date, much of the development of African irrigation has taken place in countries without sufficient rainfall, either in the Sahel zone or in the "lowveld" of southern Africa. By FAO's current estimates, there are ten sub-Saharan African countries with approximately one hundred thousand acres (40,000 ha) or more of modern irrigation. Listed in decreasing order, these include (see Table 2): Sudan (1,700,000 ha), Madagascar (160,000 ha), Zimbabwe (127,000 ha), Mali (100,000 ha), Ethiopia (82,000 ha), Mozambique (66,000 ha), Swaziland (55,000 ha), Nigeria (50,000 ha), Ivory Coast (42,000 ha), and Somalia (40,000 ha).[1] Some of these same countries have substantial areas of small-scale or traditional irrigation. If the small-scale and traditional sector is included, in eight of these ten countries over 40 percent of their total irrigation potential has already been developed (FAO 1986). Senegal, with by FAO's reckoning 30,000 ha of modern irrigation comes in an intermediate position, with five percent of its total potential exploited. However, there are other countries which are afflicted by drought but have a relatively small degree of modern irrigation development: Botswana (none), Kenya (21,000 ha), Mauritania (3,000 ha), Chad (10,000 ha), Niger (10,000 ha), Burkina Faso (9,000 ha), the Gambia (6,000 ha) and Tanzania (25,000 ha).

The importance of irrigation for Africa's semiarid lands should not be misconstrued to suggest that further investments in new schemes are necessarily what the region requires. For one thing, many of the easier options have already been exploited: witness the large commitment of water to irrigation along the Senegal River, the Office du Niger in Mali on the Niger River, and Sudan's heavy exploitation of its share of the Nile waters. Another reason for moving cautiously is the likelihood of adverse impacts in some of the areas scheduled for large-scale development, e.g., within Mali's already intensively utilized inland delta or downstream projects depending on Sudan's Jonglei canal. Even at fairly attractive sites (such as along Somalia's Juba River or Tanzania's Rufiji) there are often other reasons for moving slowly when dramatic, large projects are being planned. The priority at this juncture should

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[1]Note that country totals shown in Table 2 are based on FAO's own revision of earlier FAO figures given on a comparable table (2) of Volume 1 of this report.

TABLE 2

SUB-SAHARAN AFRICA: ESTIMATES OF IRRIGATED AREAS, 1982, IN RELATION TO IRRIGATION POTENTIAL

Country	Irrigation Potential ('000 ha)	Area Developed 1982 ('000 ha) Modern	Small-Scale or Traditional	Total	Developed as % of Potential
Angola	6,700	0	10	10	<1
Benin	86	7	15	22	26
Botswana	100	0	12	12	12
Burkina Faso	350	9	20	29	8
Burundi	52	2	50	52	100
Cameroon	240	11	9	20	8
Central African Republic	1,900	0	4	4	<1
Chad	1,200	10	40	50	4
Congo	40	3	5	8	2
Ethiopia	670	82	5	87	13
Gabon	440	0	1	1	<1
Gambia	72	6	20	26	36
Ghana	120	5	5	10	8
Guinea	150	15	30	45	30
Guinea Bissau	70	n.a.	n.a.	n.a.	n.a.
Ivory Coast	130	42	10	52	40
Kenya	350	21	28	49	14
Lesotho	8	0	1	1	13
Liberia	n.a.	3	16	19	n.a.
Madagascar	1,200	160	800	960	80
Malawi	290	16	4	20	7
Mali	340	100	60	160	47
Mauritania	39	3	20	23	59
Mauritius	n.a.	9	5	14	n.a.
Mozambique	2,400	66	4	70	3
Niger	100	10	20	30	30
Nigeria	2,000	50	800	850	43
Rwanda	44	0	15	15	34
Senegal	180	30	70	100	56
Sierra Leone	100	5	50	55	55
Somalia	87	40	40	80	92
Sudan	3,300	1,700	50	1,750	53
Swaziland	7	55	5	60	>100
Tanzania	2,300	25	115	140	6
Togo	86	3	10	13	15
Uganda	410	9	3	12	3
Zaire	4,000	4	20	24	1
Zambia	3,500	10	6	16	<1
Zimbabwe	280	127	3	130	46
Total	33,641	2,638	2,391	5,019	14.9

Source: FAO internal statistics, presented in FAO, (1986:14).

be to improve water management within existing projects and to strengthen the institutional base so that future projects achieve a better record than those now in operation--a theme to which we will return at many points in this report.

Supplementing Rainfall

The focus on drought in recent analyses of African agriculture can leave the impression that water deficits principally limit crop output at times when seasonal failures occur. In actuality, the years of severe drought (like 1983-84 in Ethiopia) are only the extreme expression of moisture deficits which occur more commonly over much of the continent. As Wigley and Farmer note (1986), in any farming system dependent on rainfall where the mean total lies near the boundary required for successful cultivation, minor deficits still can have a dramatic impact on crop yields. Even when crops survive, moisture deficits at critical periods like germination or tasselling may greatly depress the total output.

In this respect, it is often the distribution of rainfall in each growing season which can be critical for crop survival. An initial difficulty is that by the end of each dry season the moisture in the root zone will be totally depleted. The combination of a high potential evapotranspiration and rapid runoff greatly reduces the effectiveness of early rains. When the pattern is irregular, with interspersed dry periods, farmers can easily lose the germinated plants. Sometimes two or even three seedings are required to establish a crop. Again, in a large area of south-central Africa which has an extended, unimodal rainfall season of from four to five months, farmers may yet encounter a three-week dry spell at mid-season in January or February. If this comes at maize tasselling, it can also severely depress eventual crop yields. However, perhaps the cruelest moisture deficiencies are those which occur from an early termination of the rainy season, killing crops upon which farmers have expended most of the effort required for a normal harvest. Statistical analysis has shown that in many parts of Africa, drought years are characterized by an abrupt and early termination of rainfall. When this happens, farmers are left with neither food for the coming dry season nor the seed for replanting when the rains return.

The hydrological background to irrigation in Africa is dealt with in the next chapter.[1] In policy terms, what is important is to realize that the potential benefits from irrigation may be just as great in supplementing rainfed cultivation as in supplying all plant water requirements under "total" irrigation in a semiarid environment. Indeed, the numbers of farmers who commonly experience within-season water deficits and the amount of food production lost from this cause probably greatly outweigh what is gained from Africa's expensive, "full control"

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[1]Additional references useful for understanding African hydrology include Farmer (1986), Castelina and Khamala (1979), Edwards et al. (1983), Nicholson (1981), and Walling et al. (1984).

irrigation schemes. The need is clear enough: what African farmers have lacked has been a cost-effective technology for delivering supplemental irrigation to field crops.

More attention to the moisture needs of "rainfed" crops is also indicated by consideration of plant responses to improved nutrients. It is sometimes forgotten that the Asian "green revolution" achieved in high yielding varieties of wheat and rice depended upon simultaneous improvements in irrigation. Unless supplied with adequate moisture, plants cannot take full advantage of chemical fertilizers--a main reason fertilizers remain less popular in parts of Africa subject to unreliable rainfall. The high yields sometimes claimed for "improved agriculture" in Africa (see Table 3) also assume adequate moisture availability: without better water management, including perhaps some form of supplemental irrigation, they cannot be achieved by many farmers.

TABLE 3

COMPARATIVE YIELDS FOR TRADITIONAL AND IMPROVED METHODS OF CROP PRODUCTION

Crop	Traditional Varieties and Management kg/ha	Traditional Varieties and Improved Management kg/ha	Improved Varieties and Management kg/ha
Maize	1980	-	2650
Millet	710	900	-
Sorghum	970	2750	1835*
Soybean	670	-	1525
Maize/Sorghum	1500/865	-	2135/1030
Sorghum/Soybean	920/390	865/415	1305/750

*Drought at planting

Source: FAO (1983), Integrating Crops and Livestock in West Africa, Table 9 (p. 38).

Providing Forage

Observers of African livestock production are generally agreed that the marked seasonality in nutrient uptake which African livestock experience is probably the primary constraint upon the continent's livestock productivity. It is obvious that the long dry season which inhibits crop production has a similar effect on natural vegetation. Measurements taken in central Mali of the biomass fluctuations over the season show that a drop in biomass is especially marked in the savanna and delta zones, the very areas of Mali where livestock production is a traditional way of life and where the land otherwise would have relatively good carrying capacity (de Ridder, et al., 1982). The low forage productivity during the two months at the end of each dry season, in a setting where commercial feed supplies are not found and where silage is not kept, constitutes a serious limitation on livestock production.

This nutritional constraint has far-reaching effects upon the production system. For years, outside analysts have misunderstood traditional, semi-nomadic pastoralism in Africa. A main source of the low opinion held of the technical efficiency of traditional systems was the employment of individual animal production coefficients (weight gains, milk yields, etc.) when making comparisons between systems. These seem to indicate very low levels of efficiency for traditional systems in contrast to what could be obtained in lightly stocked, "improved" systems. The contrast is, of course, artificial: it is obvious that animals carried at very low stocking densities and with their physiological needs externally assisted will perform better individually (Behnke, 1985). If instead one compares the total biomass sustained per hectare under existing production constraints (heat stress, water and forage shortages, disease challenge, etc.), recent measurements from the Sahel suggest the indigenous systems outperform the "improved" practices being promoted by animal scientists (Penning de Vries, 1983).

Energy-flow measurements from different parts of Africa give similar values for pastoral populations to those obtained by wildlife, when one controls for the levels of environmental stress (Coughenour, et al., 1985). It seems that the systemic adjustments adopted by African pastoralists are similar to those used by wild species when confronted with a highly seasonal food supply. Light, hardy animals which gain condition rapidly during the short growing season but which can survive extended periods with minimum fodder and water are preferred (Price, 1981). By keeping several species which graze different plants and by utilizing the driest areas during the short rainy season, African pastoralists make a relatively efficient use of a harsh environment.

If, then, it is desirable to increase animal productivity, this transformation will not occur simply by lowering stocking rates or introducing "improved" breeds. The forage constraint must itself be relaxed. Options for doing so have been reviewed by de Ridder, et al. (1983). They find that despite its higher costs a combination of irrigation and fertilizers for forage crops are economically competitive because of the tremendous increases in output per hectare which can result (Table 4).

The incorporation of irrigated forage into African livestock systems could have two added benefits. First, (as Fig. 2 indicates), much of Africa's forage, even when abundant, is of relatively low nutritive quality. Even a fairly small addition of irrigated forage could be quite significant because of its higher nutritive quality. Second, in areas where rainfed arable farming is practiced, the poor condition of work oxen at the time when needed for plowing is another source of low productivity. Irrigated forage could be used to build up the work animals' strength before plowing begins. Indeed, a striking feature of African livestock production is the low degree of integration between the animal and crop components in the farming system (FAO, 1983). In other semiarid areas, such as in the American West, irrigated fodder production sometimes plays a large role in supporting commercialized livestock production.

TABLE 4

FORAGE PRODUCTION COSTS

Technique	Additional Productivity (in kg ha- yr-)	Forage Quality (% N)	Forage Price (in U.S.$.kg^{-1})
(1) Herbs harvested early (natural rangeland in southern Sahel)	less than 500	1,5	15
(2) Hay from fertilized pastures	5.000	1,5	17
(3) Hay from legumes in monoculture	3.000	3,0	23
(4) Forage crops (with fertilization and irrigation)			
-C_4 grasses (N and P)	75.000	1,5	22
-improved C_4 grasses (N and P)	75.000	2,5	27
-legumes (P)	25.000	4,0	43

Source: de Ridder, et al. (1983), Productivity of Sahelian Rangelands, Vol. 2, p. 84.

Stabilizing Export Crops

For the reasons already noted, Africa's large-scale estate producers of export crops like coffee, tea, or sugar have often found it advantageous to install supplemental irrigation. The prominence of public investments in "official" schemes can give the misleading impression that these are the only significant irrigation projects meriting external attention. In fact, however, Africa's most efficient irrigation systems may be in the privately owned, estate sector (e.g., Zimbabwe's Hippo Valley and Triangle estates).

As our example, let us take Kenya's estate-grown coffee. Kenya remains Africa's second most important producer of arabica coffee, with about 40 percent of national production coming from the estate sector (de Graaf, 1986). Of this, much comes from farms located in the lower and drier parts of the Kenya highlands, where supplemental irrigation is essential to insure a good crop in each season (Roe and Whitaker, 1985). As in much of southern Africa, the technology was usually based on overhead sprinklers (Wright, Rain, 1962). It is estimated there are about 16,000 ha of irrigation on Kenya's estates and large-farms, in sum total almost twice what the better known National Irrigation Board operates within its official schemes (Fleuret, 1985).

Private-sector development of estate irrigation has been underway for several decades in Kenya, Malawi, and Zimbabwe.[1] Initially, the results indicated irrigation was not cost-effective (Wallis, 1962), but more recent experience has been positive (Muller, 1973, 1975; Clowes and Wilson, 1974; Pilditch and Wilson, 1978; Fisher and Browning, 1979; Kumar, 1981), though estimation of plant water needs remains a complex task (Palmer-Jones, 1977). In coffee, supplemental irrigation is critical to induce plant flowering at times of minimal pest challenge and to prevent "die back" during droughts. The full benefits are usually observed in the yield obtained in seasons following irrigation. The stabilization this permits in high quality export crop production has become even more important during recent years when many African economies were experiencing severe shortfalls in their external earnings.

Exploiting Resource Potentials

In the longer run, a major reason for continuing the development of African irrigation systems must be the likelihood that Africa's major hydroelectric resources will be exploited. These provide an opportunity for irrigation in three ways: 1) downstream development of irrigation perimeters using water released from a dam; 2) run-of-the-river schemes using electric pumping; and 3) increased utilization of lands along the reservoir's margin.

Africa's four largest rivers, the Nile, Congo, Niger, and Zambezi, are contrasted with the world's other major river systems in Table 5 (derived from Waterbury's excellent study of the Nile). The Nile was the first to receive sustained attention, but despite its length has a relatively modest annual discharge. From Sudan northwards its power and irrigation potentials have been thoroughly exploited. However, major unexploited potential for hydropower generation remains on the two main tributaries of the Nile. Where the White Nile leaves Lake Victoria it is at an elevation of 1,136 m, in contrast to 370 m at Khartoum at its confluence with the Blue Nile; the Blue Nile originates from Lake Tana in Ethiopia at 1,800 m (Waterbury, 1979). There are at least four potential damsites on the White Nile's tributaries in southern Sudan, several more

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[1]A useful early source describing the use of sprinkler irrigation in Southern Africa is by Wright Rain, Ltd. (1962) Africa and Irrigation.

in Uganda, and a further unexploited potential along Ethiopia's tributaries (on the Atbara and Blue Nile rivers). The concern of Egypt and Sudan with conserving irrigation water predominates in most discussions of the Nile's potential--and understandably so, since both countries are nearing the limits of available water if a run of dry years should be experienced (Waterbury, 1979). However, most of this water originates upstream in Ethiopia and in the Lake Victoria basin, giving Uganda and Ethiopia substantial potential for future hydropower development. In West Africa, the Niger River, has a number of potential damsites awaiting should the regional economies ever develop to a point where the energy is required (Table 6).

The first generation of major dams in sub-Saharan Africa began with the Owen Falls dam at the outlet of Lake Victoria. Subsequent major dams creating their own inland lakes (Table 7) were built on the Volta River (Akosombo dam), the Zambezi (the Kariba and Cabora-Bassa dams), the Niger (Kainji dam), the Bandama (Kossou dam), and the Kafue (Kafue Gorge dam). At the time, these seemed large projects, but all are dwarfed by Zaire's massive hydroelectric developments on the lower Congo near Inga Falls. The upper reaches of the Congo contain further sites. The Congo River's combined power potential far exceeds what Zaire might require in the immediate future.

The point to realize when viewing a map of Africa's drainage (Figure 3) is that the continent's physical geography, with its hard rock escarpments in East and Southern Africa and with highlands around its periphery, presents many opportunities for hydroelectric development despite the aridity of much of the landscape. Geographers estimate that Africa has greater hydroelectric potential than any other continent except Asia (which it very nearly matches), almost a third more than either South America or the U.S.S.R. and well over double that of all North America (Pritchard, 1979). Yet only a tiny proportion (the least of any continental area) has been developed. Most countries have their own pet schemes awaiting implementation, on medium-sized rivers largely unknown to the outside world (e.g., Somalia's proposed Bardhere Dam on the Juba River or Tanzania's Steigler's Gorge Project on the Rufiji). If the rest of Africa were to develop its water resources to anywhere near the extent South Africa has on its small Vaal River, immense hydroelectric energy reserves could be tapped.

The existence of an attractive damsite can act as the spur to irrigation development. This happens not so much because of perceived food needs—though these are likely to figure prominently in subsequent project documentation--as because of technical opportunities associated with the dam itself. Any large engineering project in a remote site becomes difficult to justify economically, particularly when located in a poor, agricultural country. It seems that the addition of an irrigation component, with inflated estimates of eventual production, can sometimes tip the balance towards obtaining external financing. In such instances, one must remember it is the site rather than the need which was crucial. A good example would be Mali's Manantali Dam, being built by the OMVS as part of larger plans to improve navigation and power generation from the Senegal River. USAID has assisted in planning the resettlement of

TABLE 5

AFRICAN RIVERS IN WORLDWIDE COMPARISON[a]

River	Length (km)	Drainage area (sq. km)	Annual discharge (billions m^3)	Annual sediment load (millions tons)
Nile	6,825	3,100,000	84	110
Amazon	6,700	7,050,000	3,000	900
Congo	4,700	3,700,000	1,400	70
Hwang Ho	4,630	770,000	200	2,000
Mekong	4,200	795,000	400	800
Niger	4,100	1,890,000	180	40
Mississippi	3,970	3,220,000	600	600
Danube	2,900	1,165,000	200	80
Zambezi	2,700	1,300,000	500	100
Rhine	1,320	162,000	80	3

[a]Source: John Waterbury (1979) Hydropolitics of the Nile Valley, p. 14.

TABLE 6

POTENTIAL DAMSITES ON THE UPPER NIGER

Country	Site	River:[a]	Capacity (10^9 m^3)	Output (MW)
Guinea	Fomi	Niadan	5.0	85
Guinea	Kamarato	Baoule	n.a.	1.7
Mali	Selingue	Sankarani	2.0	11.2
Mali	Tossaye	Niger	2.0	n.a.
Mali	Labezanga	Niger	n.a.	n.a.
Niger	Kandadji	Niger	15.0	200
Niger	Le W	Niger	n.a.	n.a.
Benin		Mekrou	n.a.	n.a.

[a]Including tributaries of the Niger River

Source: Eckenfelder, G.V. (1980) "Hydropower plans in Nigeria," In, Smil, Vaclav and Knowland, W. E. (eds.) Energy in the Developing World. London: Oxford University Press, p. 278 (Table 22.1).

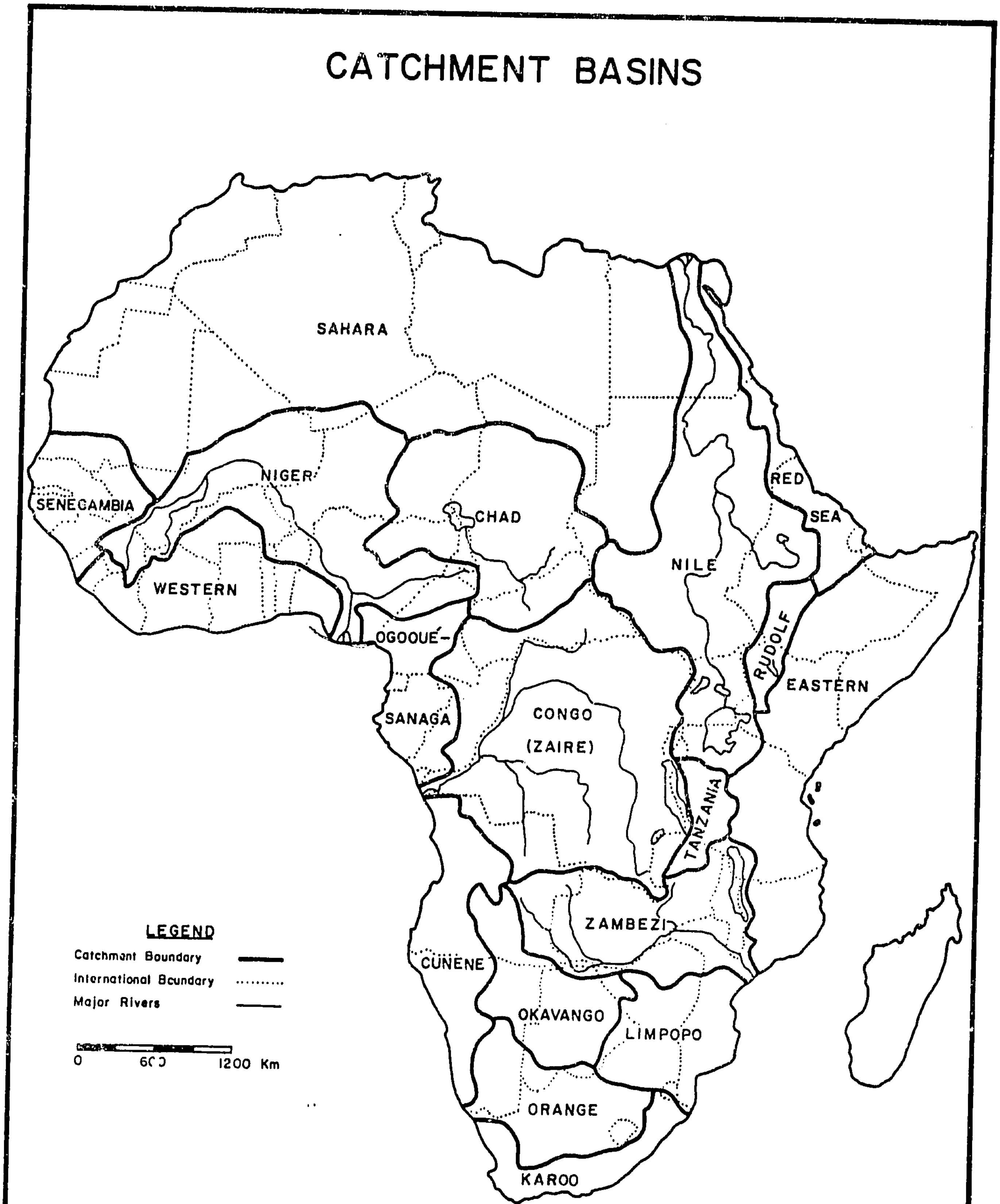
TABLE 7

CHARACTERISTICS OF AFRICA'S MAN-MADE LAKES

Dam, River & Country	Date Dam Closed	Hydro-Power (MW)	Name of Lake	Volume (km^3)	Surface of Reservoir (km^2)	Number People Resettled
Akosomba: Volta, Ghana	1964	768	Volta	140-165	8,730	88,000
Kariba: Zambezi, Zimbabwe	1958	800	Kariba	147	5,000	57,000
Cabora-Bassa: Zambezi, Mozambique	1974	2,000	Cabora-Bassa	70	3,700	n.d.
Kainji: Niger, Nigeria	1968	960	Kainji	11.5	1,280	50,000
Aswan High D.: Nile, Egypt	1964	107	Nasser-Nubia	132	5,000	120,000
Kossou: Bandama, Ivory Coast	1971	175	Kossou	29.5	1,600	100,000
Kafue Gorge: Kafue, Zambia	1970	500	Kafue Gorge Reservoir	n.d.	3,100	n.d.

Source: Adeniji, H. A. et al. (1981) "Man-made Lakes," in, J. Symoens, M. Burgis and J. Gaudet (eds.) The Ecology and Utilization of African Inland Waters. Nairobi: UNEP, p. 126.

FIGURE 3


CATCHMENT BASINS
SAHARA
NIGER
SENEGAMBIA
CHAD
WESTERN
RED
SEA
NILE
OGOOUE
RUDOLF
EASTERN
SANAGA
CONGO
(ZAIRE)
TANZANIA
ZAMBEZI
CUNENE
OKAVANGO
LIMPOPO
ORANGE
KAROO
LEGEND
Catchment Boundary
International Boundary
Major Rivers
0
600
1200 Km
FNW 86

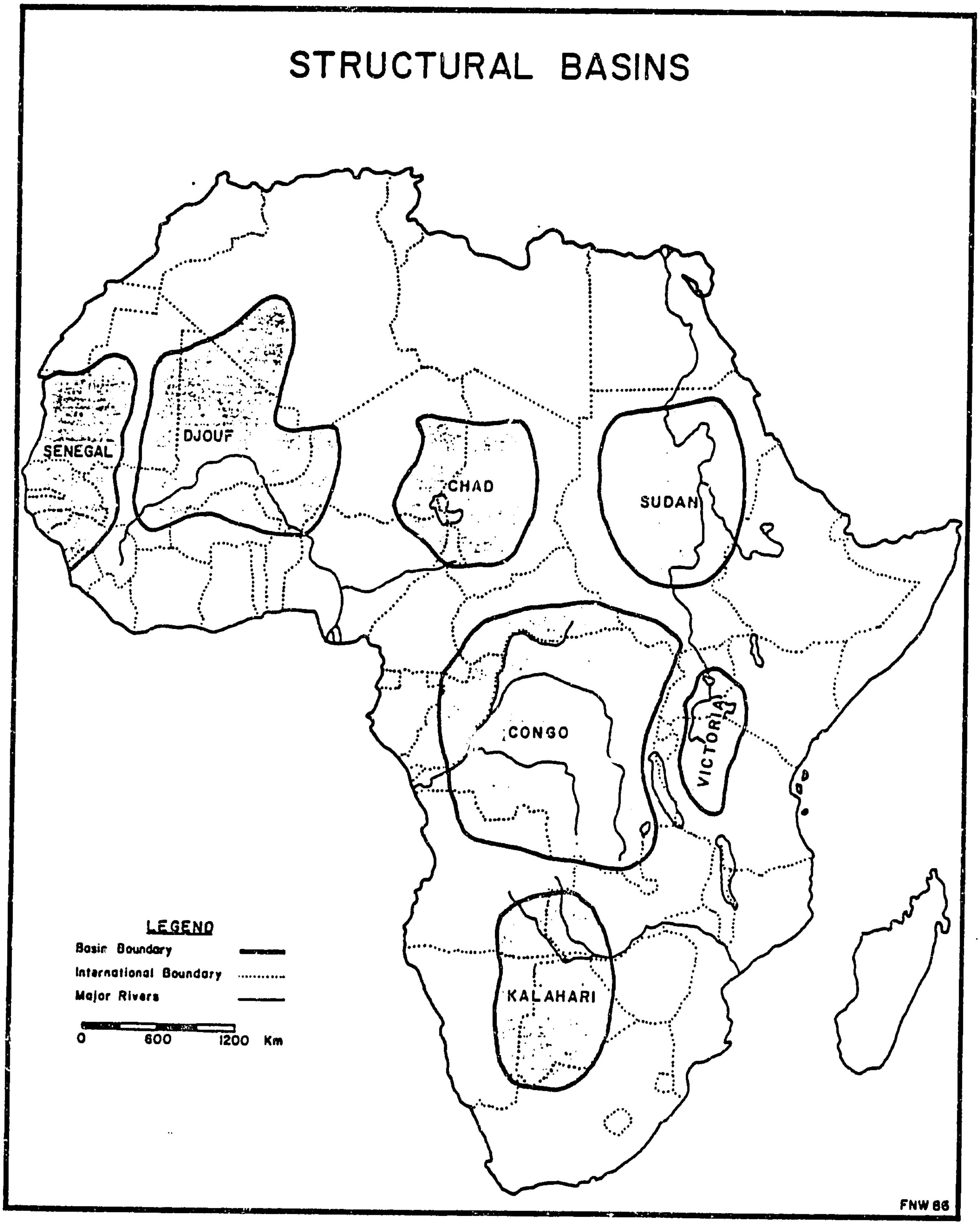
farmers onto irrigated perimeters below the dam, but it is already apparent a substantial effort will be required merely to offset the downstream production which will be lost because of the gradual phasing out of the annual flood (utilized for traditional décrue cultivation along the river banks).

When justifying large dams, proponents typically claim that large areas will be opened for irrigated production. USDA has itemized some African claims in its review of the food prospects for sub-Saharan Africa (1980:114-119). Notable among these projects are the Massengir (90-341,000 ha) and Cabora Bassa (up to 1 million ha) dams in Mozambique; the Manantali (100-340,000 ha), Tossaye (up to 800,000 ha) and the Selinguê (up to 62,000 ha) dams in Mali; a dam on the Logone River (16-27,000 ha) in Chad, another at Gorê (95,000 ha), and one at Kounbam on the Vina River (120,000 ha). Possible sites on the various branches of the Volta River might and 50-65,000 ha, with up to 652,000 ha additional if the Niger waters were to be fully exploited. To these we would add Somalia's plans for up to 223,000 ha on the Juba River, various underexploited drainages in Ethiopia and Tanzania, a large (but unneeded) potential in Zaire, and further prospects in Angola.

An even more seductive prospect arises when engineers review the overall disposition of Africa's soil and water resources. Much of Africa consists of the remnants of an ancient, pre-Cambrian rock shield. Major rivers for long periods flowed inwards into immense, internal drainage basins. The five largest, each crossed by present-day rivers, are the Djouf Basin (Niger River); the Chad Basin (the Logoni and Chari Rivers); the Sudd Basin (the Nile River); Zaire Basin (the Congo River); and the Kalahari Basin (the Zambezi River) (see Figure 4). Because of the flatness and size of these internal basins, incoming rivers dropped their sediment load, building up over time a series of inland deltas without the complications of seawater intrusion. Such sediments are deep and comparatively fertile, constituting even today special environments with unique soils and hydrologic characteristics. Mali's inland delta crossed by the Niger River constitutes one such zone; the deep sediments underlying Lake Chad another; the enormous Sudd in Southern Sudan still another; and the Okavango swamps on the borders of Botswana, Namibia and Angola, yet another. However, these are only the best known examples: numerous smaller systems with similar hydrogeological origins are found elsewhere, particularly in Zambia and Tanzania.

Two of Africa's biggest water development schemes, Sudan's Jonglei Canal and Nigeria's South Chad Irrigation Project, are located where inland swamps mark the site of ancient lakes. The Sudd, in Sudan's southern Jonglei Province, is the remains of a huge prehistoric lake thought to have covered 230,000 square kilometers (four times the size of Lake Victoria). Today the seasonally inundated marshlands fed by the various tributaries of the White Nile cover over 6,000 square kilometers (2,600 square miles). They constitute an enormous evaporating pan, from which the incoming Albert Nile (known in Sudan as the Behr el-Jebel) loses over half its discharge, i.e., a loss of around 14 billion cubic meters (Waterbury, 1979). For many years, engineers eyed the possibility of constructing a north-south bypass canal to divert the White Nile's

FIGURE 4



STRUCTURAL BASINS
SENEGAL
DJOUF
CHAD
SUDAN
CONGO
VICTORIA
KALAHARI
LEGEND
Basin Boundary
International Boundary
Major Rivers
0
600
1200 Km
FNW 86

water before it enters the Sudd's marshlands. Such a diversion would increase the flow at Malakal on the northern (downstream) side of the Sudd by 4.6 billion cubic meters. A huge project was drawn up to this effect, based on a 217 mile long canal which would permit irrigation of some 200,000 acres along its western side during the dry season; a parallel highway would connect Juba in the South with Malakal in the North (Mohamed, 1978). Because of the huge cost and concern over the environmental impact, the project was scaled down to provide drainage of only about 19 percent of the Sudd's area, and was divided into two stages. Stage one was planned for completion in 1982, but the project has ground to a complete standstill in recent years because of military insurrection in the South. Meanwhile, until 1983-84, the wetter than normal rainfalls which persisted over the Lake Victoria basin where the White Nile originates made the canal unnecessary from the standpoint of the downstream water consumption. At the same time, Nigeria's development of large-scale irrigation on the plains south of Lake Chad has been hampered by persistent drought, leaving insufficient water to irrigate more than one crop a year.[1]

It is unlikely that the failure of these two projects will deter future projects of a similar nature. In a continent where much of the land surface consists of exposed hardrock formations, the presence of rich soil and nearby water will continue to attract engineering attention. The technical possibility of producing much of Africa's food from large-scale irrigation exists, particularly if one assumes that at some future date the continent's large but underexploited hydroelectric potential can be tapped. FAO estimates there are five sub-Saharan countries with each more than two million hectares of potentially irrigable land: Angola (with 6,700,000 ha), Mozambique (2,400,000), Tanzania (2,300,000), Zaire (4,000,000), and Zambia (3,500,000). While we regard these estimates as being quite optimistic, they do at least support the notion that southern Africa in particular could support more irrigation than it does presently.

Absorbing Population

Perhaps the most compelling reason for introducing some type of irrigation within Africa over the longer run is because of the greatly increased rural and urban populations which these non-industrialized economies must support. It is well known that several of the poorer African nations are experiencing around three percent population growth per annum, with urban centers growing at more than twice this rate.[2] For

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[1]As noted in a brief article, "Drought Wrecks Africa's Biggest Water Schemes," New Scientist (8 November 1984), p. 8.

[2]African countries whose 1973-83 annual population growth was between 2.8 and 3.4 percent included Malawi, Uganda, Niger, Tanzania, Somalia, Rwanda, Ghana, Sudan, Senegal, Liberia, Zambia, Zimbabwe, Cameroon, and the Democratic Republic of Congo (World Bank, 1985).

example, in Kenya where the larger part of the country is semiarid rangeland, the growth of population over the decade from 1973-83 was three percent per annum (World Bank, 1985). It is estimated that even a decade ago, 54 percent of Kenya's farmers (in 1976-77) had holdings of less than one hectare (de Wilde, 1984).

In many African countries, there has been a relative decline in food self-sufficiency (Table 8). Thus, in a continent plagued by seasonalities and variable rainfall--as already outlined above--a dramatic stabilization and intensification of agricultural production must occur simply to keep pace with population growth. The emerging gap between rising food needs and almost stagnant cereal production figures prominently in FAO's justification for further irrigation investments (FAO, 1986). It also continues as a main motivation underlying the interest shown by national governments.

Beyond the general question of how Africa's future population will be fed, there arises specific concern over an impending "population crisis" within Africa's densely settled highland areas (though indeed less well-endowed areas may be experiencing equally severe strain because of their poorer resource base). Parts of highland Rwanda, western Kenya, or northeastern Tanzania are so densely settled that outside observers have difficulty envisaging any farming system capable of successfully absorbing the anticipated population growth. As one review of Rwanda puts it:

> Rwanda's farmland will be entirely saturated by the year 1995, with a farming population of about 5.7 million people. To achieve economic take off, farm size should be increased to 1.8 ha. Under these conditions, Rwanda's farmland is already saturated by the year 1977 at a farming population of about 3.8 million... With every passing year, Rwanda's expanding population limits the possibilities for healthy economic growth and increases the potential for loss of environmental quality. (Arid Lands Information Center, 1981:84 quoting Préfol and Delepierre, 1975)

Once the average size of family farms approaches 1.0 hectare (2.5 acres), peasants are forced to move into high density, multi-story farming of a kind quite different from the usual model. The farming systems employed by people like the Chagga of Tanzania, the Meru or Maragoli of Kenya, or in the highlands of Rwanda involve intercropping of legumes and maize, as well as multi-story cropping with bananas or coffee and sometimes fodder crops for smallstock. The density of human population exceeds 250/km^2, and where there is a bimodal rainfall regime the yearly cropping intensity may exceed 200 percent--about 90 percent in each rainy season plus some use of the "dry" season for forage production (Jones and Egli, 1984).

All the scenarios for further "improving" these already intensively utilized systems involve changes in water and land management. One option would be to take the "labor involution" route of Asian rice-

TABLE 8

FOOD SELF-SUFFICIENCY RATIOS

	1964-66 Average %	1978-80 Average %	1980 Population (millions)
Low Income Sub-Saharan Africa			
Benin	95	89	3.4
Burkina Faso	99	94	6.1
Burundi	98	95	4.1
Cape Verde	58	8	0.3
Central African Republic	92	90	2.3
Chad	100	97	4.5
Comoros	56	50	0.4
Ethiopia	99	93	31.1
Gambia	89	56	0.6
Ghana	83	71	11.5
Guinea	91	85	5.4
Guinea-Bissau	88	60	0.8
Madagascar	98	91	8.7
Malawi	101	97	6.1
Mali	99	96	7.0
Mozambique	90	64	12.1
Niger	104	98	5.5
Rwanda	99	96	5.2
Sierra Leone	91	87	3.5
Somalia	81	54	4.3
Sudan	96	98	18.7
Tanzania	96	93	18.1
Togo	96	89	2.5
Uganda	98	99	12.6
Zaire	68	66	28.9
Middle Income Sub-Saharan Africa			
Angola	110	64	7.6
Botswana	25	37	0.9
Cameroon	95	87	8.4
Congo, P.R.	26	21	1.6
Gabon	23	24	0.7
Ivory Coast	73	71	8.3
Kenya	97	96	16.6
Lesotho	93	77	1.3
Liberia	79	73	1.9
Mauritania	69	20	1.5
Namibia	100	100	1.0
Nigeria	98	84	84.7
Senegal	73	68	5.7
Swaziland	86	85	0.6
Zambia	97	79	5.6
Zimbabwe	96	113	6.9

$$^{a}\text{Self-sufficiency} = \frac{\text{Production of cereals}}{\text{Production + imports - exports of cereals}} \times 100$$

Source: World Bank, Economic Analysis and Projections Department. Cited in Singh, S., 1983, Sub-Saharan Agriculture. World Bank Staff Working Paper No. 608, Tables I and 6.

farmers, developing wet-rice cultivation on terraced lands. This is, indeed, what hill farmers in Madagascar have been doing with the dersely settled highlands were rice is already the staple crop. It might be feasible also in the areas of western Uganda where terracing is long established. A second option (really just a parastatal variant of the first) is to aim for labor-intensive "granary" schemes: perhaps a major wet-rice irrigation scheme operating at a 200 percent cropping intensity for each division or district. A third option would be to assist farmers in irrigating their own, high-value perennial crops (bananas, cassava, sugar cane, and coffee). The resource base would stay as it is, but the cropping intensity and yield might be raised. Indeed, this is what Chagga farmers in Tanzania's densely settled Kilimanjaro Region have done at their own initiative.

A fourth option would be to reclaim the valley-bottom "swamps" which constitute the last reserve of underutilized land within much of the highlands zone. Here, too, farmers at their own initiative have been moving downwards:

> ...to clear, develop and farm the swamps. This process began not too long ago, and continues. Papyrus or other cover is cleared. Soil is worked into ridges and drainage ditches with hoes. Crops are planted in the dry season...when they cannot be grown elsewhere, but not in the rainy seasons.... Beans and sweet potatoes are the principal marsh crops. While marsh cultivation is physically demanding, the results are impressive. (Jones and Egli, 1984:23).

Because the alluvial soils capture nutrients deposited from the upper slopes and enjoy an extended moisture regime, the output from these marshes is "much greater than their proportion of cultivated lands would suggest." For western Kenya, Toksoz (1981) notes there are about 800,000 hectares of land with impeded drainage, of which he thinks at a "conservative estimate" 600,000 hectares could be reclaimed by a combination of drainage and flood protection measures.

There remain serious difficulties in applying conventional drainage and irrigation technology within these kinds of farming systems, most notably the dangers of an increase in soil acidity (bringing with it heightened levels of iron and aluminum toxicity), and destruction of the water holding capacity of the natural system. However, to proponents of technological intervention it still seems reasonable to assume that an intensification of crop production commensurate with population growth will require <u>some</u> form of improved water management. The specific details of a modern-sector equivalent to farmers' own spontaneous adaptations remain unclear, but the case for further experimentation remains strong (Turner, 1986).

We conclude from this review of arguments for increased irrigation investment in Africa by noting that they are based in large degree on theoretical advantages. The technological promise offered by irrigation is one more example of the gap between present performance and ultimate potential within Africa. On the other hand, <u>if</u> African countries could be developed in ways that exploit their existing resource potentials, irrigation is likely to become increasingly important. Those willing to act upon this premise (which include several African governments) would see Africa at a stage in its irrigation development comparable to where Asian countries were in the 1950s. The priority would then lie in strengthening the weak institutional and technological base, as a preparation for increased reliance on irrigated production in the future.

If, on the other hand, one examines present performance and economic constraints (impinging on producers and national economic institutions alike), irrigation appears to be an inappropriate investment. Poor countries adopting irrigation will find themselves locked into supporting high-cost, subsidized production of commodities they do not really need.

The Case Against African Irrigation

Steinberg's world-wide overview of irrigation notes there are certain circumstances where irrigation investment represents an "inappropriate" policy response. The specific constraints warned against include (Steinberg, 1983:37-38):

- when there is an unresolved presence of irrigation failure in the past;
- if irrigation intrudes into a fragile environment (ecological or social);
- when economic policies or institutions are weak;
- where there are poor agricultural pricing policies, ineffective marketing facilities, high transport costs, or the unavailability of required agricultural materialsl;
- if irrigation involves massive dislocation of peoples;
- if it will exacerbate social tensions;
- if the institutional capacity to manage irrigation has not been demonstrated or if overall management is weak;
- if a long-term donor commitment is unlikely or if the donor lacks the required disciplinary skills and monitoring capability.
- if required socioculture knowledge is lacking,
- if the legal basis is clouded or if dispute resolution is likely to be faulty.

As it happens, a majority of Africa's formal irrigation projects have been implemented under circumstances where several of the above contraindications were present. In Africa's more remote environments one typically finds that many earlier projects failed, that the environment itself is fragile, that transport costs are high, that implementation of an externally designed project will exacerbate social tensions, that marketing is poorly organized, and that the institutional capacity to manage irrigation is almost nonexistent. In a few extreme instances, such as in Nigeria's ill-fated Bakolori project or Kenya's Bura Settlement, nearly all the above indicators would have warned against proceeding. Do we then conclude that any further financing of major irrigation projects at this stage in African development should be avoided?

Those opposed to further capital investment in African irrigation generally rest their case on three lines of argument: 1) the low performance of many existing schemes; 2) the higher returns from investments in rainfed agricultural projects; and 3) the question of the appropriateness of the technology itself under African economic circumstances.

Weak Irrigation Performance

Technical experts working in Africa widely believe that irrigation projects have a poor record of performance. An article in Engineering News for January of 1985 mirrors these opinions:

> None of the water experts contacted could point to any large agricultural project built over the past 10 years in black Africa that have made a dent in the current famine. "Africa has borne the brunt of a lot of bad advice, bad engineering and bad intentions and they are paying the price for it now," says a U.S. engineer who is the area manager for Africa at a major international water resources consulting firm. (Engineering News, 1985:10)

Such views are based upon actual project experience, not on the published record. Taking the published figures at face value, irrigation, while expensive, seems to have been justified in many instances. The largest donor supporting African irrigation has been the World Bank. It claims to have substantially achieved appraisal targets on several of its larger African projects, as evidenced in data published by the FAO Investment Centre (partly funded by the World Bank). In an Africa-wide consultation on irrigation held in April of 1986, FAO made further use of the Bank's data. A background paper on irrigation economics showed economic internal rates of return for the Bank's African projects as follows: SEMRY I (23 percent), SEMRY II (20 percent), Lake Alaotra (22 percent), Morondava ("extremely low"), Mopti Rice (17 percent), Rahad (19.5 percent), and Senegal's river polders (8 percent). It concluded that with the exception of Morondava and Senegal's rice polders, the Bank's other African irrigation projects "pass the test successfully" (FAO, 1986:17).

Less sympathetic observers might draw different conclusions. The FAO economics paper itself noted the 20 percent rate of return for SEMRY II claimed yields of 9.5 tons of paddy/ha/year, based on double cycle cropping, and queried whether such yields "could be easily maintained or replicated under African conditions." While the Bank has done subsequent evaluations, the figures it is willing to release are those obtained at project completion "when projects were still benefitting from very intense support and supervision, and considerable pressure on the part of the donor" (FAO, 1986:18).

The extrapolation of aggregate yields from a sampling of plots to derive official production statistics tends to yield upwardly biased estimates of irrigated production. In the case of Senegal's small-scale rice perimeters, the agency responsible (SAED) claims its field surveys document relatively homogeneous yields of about 5.2 t/ha, with intraperimeter variances similar to those seen between perimeters. An independent analysis of some of these same perimeters by Fresson gave a rather different picture. For example, on the Thialy perimeter while SAED recorded mean yields of 5 t/ha, with a standard deviation of 0.685, Fresson's larger sample gave mean yields of either 3.6 t/ha (under optimistic assumptions) or 2.9 t/ha (under pessimistic assumptions), with a standard deviation of 1.814. Even under the optimistic case, the modal value obtained by the largest number of farmers was barely over 2 t/ha (Fresson, 1978). Fresson explains the discrepancy as follows. It seems that under SAED's multi-stage sampling design, each perimeter was represented by only six plots. From these two square plots of 10 m^2 were "randomly" drawn.

> Observers who actually attended the sampling for the last winter harvest season (1977) report that the choice was made on the basis of the ripeness of the crop at the time. The selected plots were those which ripened first, corresponding therefore to those having had the best watering and attention. (Fresson, 1978:29)

In extending such results to a perimeter as a whole, agency staff typically overlook areas given over to roads and drains, waterlogged or salinized fields, and large sections which for some reason could not be irrigated in a given season. It is not unusual in Africa to find that farmers' effective yields may be about half of what is claimed by the parent irrigation agency.

Even if one accepts the World Bank's rates of return on its irrigation projects, one can question what such estimates really mean. Take as an example Sudan's Rahad project, shown as having achieved a 19.5 percent economic internal rate of return. USAID was a minor co-financer in this project, and thus provides an independent evaluation (Benedict, et al., 1982) carried out when the project had been in operation for four years. The USAID report cites IBRD sources indicating the original cost estimate of 99 million dollars was revised in 1975 to 240 million and again in 1979 to 400 million dollars--a 404 percent increase. While IDA's contribution rose from 42 to 67 million dollars, the Sudanese Government's went from 25 to 235 million. The Rahad Corporation established to implement the project ran current account losses of between 7-12 million Sudanese pounds in each year between 1979 and 1982, not including any loan amortization. The project design aimed at nearly total mechanization of groundnut and cotton production. In the two years prior to evaluation, production costs on these two official crops exceeded revenues and over 80 percent of the production costs were paid directly to the Corporation without passing under tenant's discretion. Cotton yields had been estimated at 6 kantara/feddan; in 1980-81, they appear to have been about 2.5 kantara/feddan. Rising labor costs meant that farmers' profitability was deteriorating even more rapidly than yields. Heavy use of imported insecticides--with eleven sprayings of cotton per season--had brought about an emergence of resistant strains of major cotton pests as well as of malaria carrying mosquitos. Public sanitation on the scheme was described as "appalling." The new villages being built in the South lacked even the few amenities provided to the older northern villages before the Corporation got into such financial difficulty. In short, the problems inherited by the Rahad scheme after it went into operation were just as severe as any being experienced in the local environment before its creation.

In point of fact, Sudan's irrigation projects are among the better ones in sub-Saharan Africa. Here, "successful" agricultural projects are the exception rather than the rule. Gray and Martens found that among thirteen Sahelian development projects they studied, at best only two or three were viable (1980:64). Of the seven irrigation schemes operated by Kenya's National Irrigation Board in 1982, only one (the Mwea Scheme) was operating at a profit (Fitter 1983, Fleuret 1984). In Niger, of the 9,000 ha of irrigated perimeters established since independence, only about 5,500 were still in production by 1982 (Zalla, et al. 1984) estimate that despite donor-financed new projects, about 12 percent of Niger's irrigated land has been going out of production in each year. The problem is long-standing: even the French colonial government found it had to subsidize Senegal's irrigated Richard-Toll perimeter by amounts between 8-50 million CFAs annually every year between 1946 and 1960 (USDA 1980). Similarly, the French financed Office du Niger required annual subsidies every year during its first two decades of operation (de Wilde 1967).

Perhaps the best documented recent attempts by an African government to develop large-scale irrigation come from Nigeria, where the high oil prices in the late 1970s coincided with a political decision to accelerate "development" in the country's semiarjd North. Ajao (1980) describes how the Yobe Irrigation Scheme near Lake Chad which was begun in 1959 became the basis for ambitious plans to establish four major irrigation projects totaling 10,000 acres along the Yobe valley. Yet, as of his writing, only 2,500 acres were effectively under irrigation. Because of problems of weed infestation, salinity, and mismanagement, the Bornu State Government continues to operate the scheme at a loss, for political rather than economic reasons. Other authors make it clear that this has been a general pattern in most of Nigeria's formal irrigation projects (Palmer-Jones, 1981; Ejiga, 1970; Adams, 1983, 1984; Igozurike and Diatchavbe, 1982; Andrae and Beckman, 1985).

The contrast between anticipated and realized performance in irrigation is sharpest for poor, arid countries like Mauritania or Somalia which can least afford mistaken investments. Facing the prospect of massive food imports, the Somalia government in its 1983 National Plan states that the "main thrust" for developing agriculture will be achieved "by expanding the area under irrigation as rapidly as may be possible" (SDR, 1983). The plan lists irrigation projects totaling over 40,000 ha, not counting the proposed Bardhere Dam on the Juba River which might eventually irrigate 223,000 ha (SDR, 1983). In several instances, the projects are directed at rehabilitating earlier schemes which subsequently failed.

Somalia's actual performance in establishing irrigation can be judged from the history of the Afgoi-Mordile project.[1] The project was one of several originating from a 1967 preinvestment survey undertaken by British consultants under United Nations Development Program (UNDP) financing. The project plans drawn up by the consultants were submitted to the African Development Bank (ABD) group for financing in 1972. A joint company (LIBSOMA) was set up to act as the implementing agency. The whole of the 3,000 ha intended for the schemes was cleared in 1973, but only half was leveled (of which some 540 ha needed releveling by 1981). The 1973-74 oil price increases led to immediate cost overruns, made worse when in the same year drought caused a diversion of scheme equipment to resettle starving people. When the rains returned, those settled in the schemes preferred to do their own cultivation. Machinery on the scheme was operated by a parastatal company, which was unable to get sufficient spare parts to keep the Russian tractors working. A different parastatal was made responsible under the Ministry of Agriculture for crop marketing, but was forced to buy at low controlled prices. Shortages of labor continued. Meanwhile, the drought caused a loss of cover in the catchment and the river began carrying a huge volume of silt. This clogged irrigation pumps and distributory canals, leading to rapid weed growth. Yields were reported as having been "very much lower" than those used in the initial appraisal. The areas actually cropped began at 254 ha in 1974, rising to a peak of 1,656 ha in 1976 but thereafter declining back to 252 ha in 1980. Equipment problems have intensified, with some units left idle for three or more years awaiting spares. The ADF appraisal report recommending a fresh injection of capital concludes:

> ...the present staff are clearly unable to cope with the problems of adequately maintaining a large fleet of tractors and associated equipment... (ADF, 1981:15)

Space precludes itemizing more case histories like the one just described, which could be duplicated from many other African irrigation projects. The research for this report did not permit field visits to a cross-section of African schemes, but there are several other comparative reviews on record: A Wageningan study of EEC financed African projects (van Steeklenburg and Zijlstra, 1985), as well as a CILSS/Club du Sahel Working Group (1980) and Brondolo (1985) on Sahelian irrigation projects. In Montgomery's comparison of irrigation system performance (1983), the

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[1]All information on the Afgoi-Mordile project derived from an African Development Fund report (1981).

Mwea Scheme was the only African example which was rated even moderately successful. In general, it seems that many African irrigation projects are characterized by poor design, cost overruns, incomplete implementation, numerous agronomic and technical problems, low rates of return on capital, and a high degree of alienation by farmers (see Chapter Four).

There are a few exceptions. The World Bank's claim to having mostly successful African projects remains a testament to one donor's faith in irrigation technology. However, the African experts drawn upon in formulating this report did not share the Bank's optimism. From their own field visits and personal experience, most regard African irrigation as a source of continuing economic and technological problems far outweighing the meager benefits which participating farmers have obtained to date.

Returns to Alternative Investments

The second main line of argument against African irrigation is quite simply that the returns to investing in rainfed agriculture, or perhaps nonformal small-scale irrigation, are higher. The issue arises partly because formal irrigation projects in Africa have been so capital intensive, but also because in a number of countries a large share of the irrigated production comes from the nonformal or "traditional" sector (Table 9). Investment in expensive new schemes is seen as a double mistake: first, because the rainfed agriculture which presently produces most of Africa's food is starved for capital; and second, because where irrigation is important the significant output comes from producers who do not receive assistance under official schemes.

Of course, investigation of comparative returns would normally come under irrigation economics (Chapter Eight). It is dealt with here because it is so central to African policy choices when deciding whether to persist in funding irrigation projects. The key research examining this question was carried out by Stanford's Food Research Institute under AID funding in the late 1970s, reported in a (1981) book by Pearson, Stryker and Humphreys (among others), Rice in West Africa and in various individual papers (see especially Stryker, 1978).

Rice in West Africa was a pivotal study in several respects. It grew out of AID's concern following the 1972-73 Sahelian drought whether to support the kinds of capital-intensive irrigation projects being proposed, or whether to assist instead the rainfed and nonformal subsectors--an issue which has come back to center stage following the 1983-84 drought. To our knowledge, it remains the only sophisticated, in-depth treatment of the economics of a major African crop which explicitly analyzes the returns from an array of technological options, including several forms of irrigation. Rice is Africa's most important irrigated crop, and (except for Madagascar) West Africa is the main center of local consumption. The study draws a crucial distinction between private and social profitability, essential for analyzing policy

TABLE 9

IRRIGATED RICE PRODUCTION IN MAJOR PRODUCING COUNTRIES

(1982)

	Total Production	Upland	Wetland	Modern Irrigation	Modern Irrigation as Percent of Total
	----------------'000 t			----------------	
Madagascar	2,000	400	1,000	600	30
Nigeria	1,400	350	910	140	10
Sierra Leone	550	300	250	0	0
Ivory Coast	500	425	75	0	0
Guinea	275	180	95	n.a.	n.a.
Liberia	241	229	12	0	0
Zaire	255	243	12	0	0
Tanzania	200	90	100	10	5
Mali	250	13	87	150	60
Senegal	100	25	65	10	10
Ghana	90	67	5	19	21
Mozambique	62	3	12	47	76
Cameroon	60	15	15	30	50
Niger	29	2	19	8	28
Chad	47	3	41	3	6
Kenya	43	11	n.a.	32	74
Burkina Faso	40	2	30	8	20
Gambia	35	2	29	4	11
Guinea Bissau	30	15	15	0	10
TOTAL	6,207[a]	2,375	2,771	1,061	17

[a]Total production of rice in all sub-Saharan Africa is estimated to be 6.45 million tons.

Source: FAO Investment Centre, 1986, Irrigation in Africa South of the Sahara, Table 18. Rome: FAO.

choice in settings where various aspects of production and marketing are heavily subsidized. It includes chapters on the drier, Sahelian nations (Senegal and Mali) as well as the wetter countries (Ivory Coast, Liberia, and Sierra Leone). And, for non-economists, it includes useful methodological appendices on shadow prices estimation.

What emerges clearly is the fact that much of the larger share of Africa's existing rice production comes from upland and "swamp-rice" systems developed by farmers themselves with minimal public assistance. FAO statistics indicates that this continues to be the case despite a decade's further investment in medium- and large-scale irrigation schemes (Table 9). Close examination of these figures supports the conclusion that while irrigated production of rice is important, the proportion grown on officially-assisted "modern" schemes is low in all but a few countries (notably in Kenya and Mozambique and to a lesser extent in Mali and Cameroon).

Technical Appropriateness

The third reason for avoiding irrigation in Africa is simply because in their contemporary form, irrigation technologies are inappropriate. A farmer choosing to irrigate is moving into an intensification of crop production by increasing the capital invested in farm equipment, designed to move water from a reliable source to growing plants. For a commercial operator trying to maximize profits despite uncertain rainfall, this transition can be highly rewarding. The literature provides many examples from dry lands in Israel, Australia, and the western United States which shows that when the right conditions exist, a demand-led diffusion of irrigation technologies will occur.

However, it is not difficult to specify a range of situations where the adoption of irrigation would not constitute a sensible production strategy. It obviously may not pay if crop returns are low, setting a ceiling on the amount of capital farmers will invest in the production process. Irrigation also does not provide much advantage if the water supplies are themselves likely to fail. It may not be feasible if the other inputs required for intensified crop yields are not readily available. It doesn't become attractive if farmers lack secure claim to their land, inhibiting on-farm capital improvements and shortening the time frame for recouping investments. And, finally, irrigation is an unlikely choice in settings where poor farmers face heavy demands upon scarce capital.

In all of the above aspects, African smallholders differ from the larger-scale, mixed farmers who have adopted irrigation in places like Texas or Idaho. Without security, attractive prices, available inputs, access to credit, and reliable water supplies, irrigation itself ceases to be an attractive technical option. The spread of demand-led irrigation technologies has occured tropical only under special circumstances, e.g., among Kenya's coffee estates. Otherwise, it has not yet become a general feature of African farming. This observation should constitute a warning that usually a suitable match between farmers' needs, capabilities, and the introduced technology remains to be achieved.

Many of the projects reviewed in this report were introduced at government initiative. In virtually every case, the choice of technologies to be installed, and even in many instances the crops to be grown, are made at a distance by those without detailed knowledge of local conditions and constraints. Typically, design consultants determine the physical layout, perhaps following broad guidelines established by an earlier FAO/UNDP survey. Donors often dictate the choice of machinery (pumps, gates, etc.), or else this may be done under ministerial procurement. Economists doing the project appraisal specify the crops to be grown and the targeted cropping intensity. In this extended process--which has grown even more convoluted as multi-donor financing becomes common--farmers and local extension agents do not become involved until after most key decisions have been taken on their behalf. African irrigation presents many examples of bureaucracy-led and donor-led technology choice.

Perhaps this explains why one sees so many examples of inappropriate irrigation equipment during site visits. Sometimes the problems arise because of a failure to consider local contexts. Wire gabions may be installed at remote sites where the wire is likely to be "borrowed" by nomads, or metal gates used without locks to protect them from theft and tampering. Sometimes the equipment is simply too sophisticated: self-leveling water control devices, which become easily clogged, or types of plastic pipe subject to degrading in intense sunlight and to termite attack. But much the largest source of difficulty (which we discuss in Chapter Four) has been imported "orphan" equipment, which cannot be served and repaired locally. In countries without an established irrigation industry, the maintenance of imported equipment becomes a continuing administrative burden, exceeding the support capacities of both the private and the public sectors. The effect is to greatly shorten equipment life, which in turn further raises irrigation costs. All across Africa, one finds broken down pumps which donors installed to provide household and irrigation water.

A less obvious form of technological mismatch arises in respect to the choice of crops irrigated. On Africa's official schemes, by far the most common crops grown are rice, sugarcane, and cotton, with wheat and vegetables making up most of the balance. The usual way of representing production statistics under the heading of "cereals" and "fiber crops" disguises the extent to which just these four crops--paddy, sugarcane, cotton, and (in West Africa) wheat--predominate. (For details on the agronomy of sugar, rice, and cotton, see Chapter Five.) Outside experts may see this concentration upon a few crops as being a positive feature. After all, it has been the irrigated production of rice and wheat which made possible the "miracle" high yielding varieties which revolutionized agricultural output in places like northern India or northern Mexico.

As it happens, however, these four crops are subject to economic and agronomic difficulties in tropical Africa, to such an extent that they have made irrigation itself unattractive. In regard to sugarcane, the difficulties are economic. Tropical producers find themselves in competition against heavily subsidized EEC sugarbeet production. Even relatively efficient African producers are unable to compete in world export markets. This particularly affects irrigated cane-growing, because of its necessarily higher production costs.

For cotton, the difficulties are related to the ceiling on prices set by the competition from cheap synthetics, and to the rapid emergence of serious pest problems. African cotton growers often also produce sorghum, millet, legumes, and pulses for their food. These crops can act as hosts to many cotton pests, providing a nearby refuge whenever spraying of cotton commences. Cotton is an input and labor intensive crop, competing directly with food crops for household resources throughout the production cycle. Unless all recommended measures are effective, the yield obtained falls off dramatically. The involvement of intermediary agencies to provide spraying and to handle the crop can also mean that farmers are paid only about half of the already low international price.

Britain's desire for cheap cotton was the original motivation for the Gezira Scheme, Africa's largest single irrigation project (Barnett, 1977). Calculations by Faki (1982) show that in fact by the late 1970s of the four main crops tenants grew, cotton was the least profitable both per man day and per unit of water consumed (Table 10). Simmons obtained much the same results for irrigated cotton in Niger, where the returns per day were less than half those from rainfed cowpeas intercropped with millet, and one-fourth those farmers could obtain from their own, small-scale irrigated onion growing (Zalla, et al., 1984). We discuss this issue further in Chapter Eight on irrigation economics; suffice it to note here that cotton and rice are among the least profitable of the irrigated crops African farmers might choose to grow. One cannot help but to agree with Faki's conclusion that these crops are emphasized on official irrigation schemes to serve overriding national interests, irrespective of the returns farmers actually obtain.

TABLE 10

CROP RETURNS TO TENANT FARMERS IN GEZIRA, 1977/78
(Sudanese/feddan)

	Cotton:	Wheat:	Peanuts:	Dura:
Gross Returns (s/Fed)	24.451	41.594	21.567	17.430
Total variable costs (s/Fed)	12.420	28.416	12.557	10.439
Gross margins (s/Fed)	12.031	13.178	9.010	6.991
Labour input (man-days/Fed)	14.000	5.000	5.800	5.800
Gross margins/man-day (s)	0.859	2.636	1.553	1.205
Water consuption (m^3/Fed)	3552.000	2238.000	2030.000	1224.000
Gross margins/000 m^3water (s)	3.387	5.888	4.438	5.712
Gross returns to water (s/'000 m^3)	6.884	18.585	10.624	14.240

Source: Hamid Faki (1982) "Disparities in the Management of Resources Between Farm and National Levels in Irrigation Projects, Example of the Sudan Gezira Scheme," Agriculture Administration, vol. 9, p. 55.

Rice, when grown in Africa, has its own problems. The outstanding success of dwarf, high yielding varieties in Asia led many observers to hope the same "miracle" might be repeated within African wet-rice cultivation. But the situation on the African continent is different in a number of key respects:

- Only about 11 percent of sub-Saharan Africa's rice acreage is irrigated, lowland rice (IITA, 1985). Except in Madagascar, there is little possibility that high yielding wet-rice varieties could be adopted directly or even added as a second cycle crop in the manner achieved in much of Asia.

- When introduced into Africa, IRRI's Asian-derived cultivars have encountered different pests and diseases for which they lacked resistance (Zan et al., in Hawksworth, 1984:64-70). Iron toxicity has been a problem, as has also rice blast (*Pyricularia oryzae*).

- Yield reductions caused by competition from weeds have been severe. Here the problem is that because African rice (*Oryza glaberrima*) was domesticated from the annual wild rice (*Oryza barthii*), anyone growing new varieties or Asian rice faces immediate problems of hybridization and competition from already established varieties which then become weeds in the farmers' fields (Harlan, 1975). Weed growth becomes so vigorous in some forms of swamp-rice cultivation that farmers traditionally abandoned fields after only a few seasons (Owen 1973).

- On modern schemes, weed seed tends to become incorporated with the paddy and spreads thereby to other projects.

- Rice planted on well-drained, upland soils has proven very sensitive to the short dry spells so characteristic of African rainfall regimes. Introduced varieties often show relatively poor tolerance of drought.

- Economic circumstances in Africa differ from those found in the major rice producing countries of Asia. The water itself may be more expensive (if from a pumped source) and its supply more problematic (because of seasonality, a high silt load, and salinity). Many countries cannot afford to import fertilizers and insecticides. Adequate engineering support cannot be obtained locally, and support services are missing. The farmers themselves do not live in tightly integrated households capable of supplying extra labor required for intensified production.

For all of these reasons, while breeding of superior varieties continues at IITA in Ibadan and through WARDA in Monrovia (the main sources of rice improvement in West Africa), imminent breakthroughs are not anticipated.[1]

Even wheat, which requires little labor when mechanized and has been relatively trouble free when grown under irrigation at higher altitudes, has been much less successful when grown in Africa (Byerlee and Longmire 1986). Production costs have always been high; Eigher and Baker report FAO figures showing that in 1966 irrigated wheat in Nigeria cost 168 per ton to produce as compared to the landed cost of imported wheat at 84 a ton (1982:135). By 1982, Northern Nigerian wheat cost about 1,200 dollars per tonne to produce, exclusive of any capital repayment charges, at a time when the c.i.f. price in Lagos for North American wheat was under 200 dollars per tonne (Andrae and Beckman, 1985). The factors behind this dramatic difference are detailed by Andrae and Beckman in an angry presentation of Beckman's research on the appalling performance of Nigeria's larger schemes. Aside from many errors of judgement, the basic fact remains that wheat is poorly suited to production in the hot tropics, and performs least well under highly mechanized attempts to grow it on variable and difficult soils such as one finds in most of lowland Africa. Whether grown in Nigeria, Mali (Moris, Thom and Norman, 1984), or Sudan (Pearson, 1980), mean yields remain stubbornly below 1.5 tonnes/ha, giving insufficient returns to cover production costs let alone scheme repayment charges.

The issue of the import content of production becomes of overwhelming importance when countries are experiencing acute balance-of-payment difficulties. We have just seen that the notion a country "saves" hard currency by resorting to irrigated production of cereals is very misleading. Tractorized farming in Africa tends to have a high import content, as do also truck transport and the employment of fertilizers, insecticides, and herbicides. Until recently, because of

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[1]The key sources on African rice production are Buddenhagen and Persley (1979), Are (1981), and Pearson et al. (1981). See also Chapter Five.

the strong association between high input farming and "modern" or "scientific" agriculture, policy makers in Africa were slow to recognize that some types of husbandry are inappropriate economically even when desirable technically.

Under Africa's present economic difficulties, large-scale irrigation is economically inappropriate in five respects: 1) it usually requires a large injection of hard currency during initial construction: 2) the machinery installed (pumps, grain dryers, etc.) will require continuing hard currency support throughout the lifetime of the project; 3) high input farming needed to achieve high yields has a high import content; 4) those projects located at remote sites will incur high transport costs, which also have a hidden foreign exchange content (fuel, vehicles, and spare parts); and 5) most large-scale schemes are provided with expatriate staff, generating further losses of hard currency. When poorly managed, these schemes evidence such low productivity and rapid deterioration of physical plant that countries are unable even to repay the loans under which they were constructed.

The Policy Context

African countries are conspicuous for not having policies towards irrigation, with the exception of those few like Egypt or Somalia with no real choice but to embrace irrigation if they intend to develop the agricultural sector. One sometimes suspects 'policies' are invented by economists to give after-the-fact coherence and direction to the description of aggregate national behavior. In this instance, however, the presence of two competing viewpoints about whether or not to invest in irrigation does make the issue a matter of choice. If African countries prefer to see irrigation as a necessary form of agricultural modernization, the high costs of the technology mean that this preference is in effect a policy decision even though leaders may evade facing up to the opportunity costs. Irrigation in sub-Saharan Africa is, as we have made clear throughout this chapter, a demanding, risky and expensive option. Any country choosing to fund irrigation projects should only do so if the advantages and disadvantages have been carefully weighed.

Institutional machinery for making sector-level decisions is often poorly developed in Africa. To the extent that informed decision-making occurs, it is likely to be vested in ministries of planning and finance. The decline in the overall rate of investment in irrigation in recent years can be attributed to the aggregate balance-of-payment problems many African countries have experienced, so that an increasing proportion of incoming capital is used in debt servicing rather than for the financing of major new projects. Thus, there has been a de facto curtailment of commitment to new irrigation projects, but it results from generalized economic problems rather than from a considered review of technological options within the agricultural sector.

The choice of technologies within the agricultural sector is, as already noted, a matter decided above the level of the individual farm. The nature of irrigation in the case of large volume supplies derived from dams or major pumping stations puts it beyond the reach of unaided smallholders. Thus, countries cannot wait for demand-led technology choice. Instead, investment decisions will occur because irrigation agencies and donors act as pressure groups, promoting the development of particular projects and sites, or because planners at the ministry level have decided irrigation is necessary for promoting national agricultural development.

The capacity of irrigation agencies, donors, and planners to make sensible decisions about African irrigation is still only weakly developed. A major purpose of this report is, then, to provide descriptive and analytical information which will highlight the issues at stake. In Chapter Nine, on irrigation management, we return to the question how a planning function might be institutionalized so that better quality investment decisions will occur in the future. At present, there are only a few African countries which have a nucleus of technical staff (economists, engineers, and agronomists) assigned to carry out irrigation planning. The lack of systematic information on present performance and the many contradictions embodied within existing programs have made it difficult for African ministries of agriculture to formulate sensible policies.

There are five basic questions we feel ought to be addressed in order to put the choice of irrigation technologies on a firmer base within sub-Saharan Africa.

1. Are the present field difficulties simply a natural consequence of "first generation" technological interventions within poorly developed economic systems? If they are, more investment to provide adequate infrastructure and support is justified, particularly in view of Africa's underexploited irrigation potential. If they are not, a larger volume of activity will only increase losses.

2. How serious are the various environmental limitations--natural, economic, social, administrative and political--and what is their varying influence in different settings or with regard to alternative irrigation technologies? Past programs paid scant attention to either the setting or the choice of irrigation technology. It now seems obvious that both are critical dimensions in African contexts. Furthermore, the highly variable situations encountered in many countries suggest that no single type of irrigation will suit all conditions.

3. Is some form of irrigation essential in order to safeguard African food security over the longer run? Here one's attention shifts toward evaluating the long-run population carrying capacity of Africa's agricultural lands. The central role of improved water management as a precondition for the adoption of higher yielding varieties in Asia raises the possibility that a similar transformation may be necessary to increase the productivity of African agriculture.

4. Can less expensive and more sustainable types of irrigation be devised which are suited to smallholders and which can be applied for growing lower value crops? It is plain that if irrigation remains a high

cost, high import content technology, it will be confined to schemes of an agro-industrial character ("estates"), or their parastatal equivalent (the Gezira/Mwea model).

5. If the absence of middle-sized, operator controlled units makes it unlikely that technology choice will be demand-led, what institutional alternatives can be developed as surrogates for farmers' own initiatives? How do African governments get the bureaucratic parastatals and multinational corporations which predominate within the irrigation subsector to behave responsibly, cost-effectively, and innovatively? Who should do the planning and supervision of irrigation development?

These are fundamentally "meta-issues," which will remain unresolved if attention is directed primarily at the project level. A principal conclusion of this study is that many African countries need to evolve a sector-wise approach towards irrigation development (see chapters eight and nine). We are not for a moment proposing that countries require a uniform, all-purpose institutional or technological model, nor are we endorsing the kind of simplistic, long-run demand projections some have used to support an undifferentiated commitment to expansion of irrigation. But we do claim that the design of effective individual projects is difficult if no institutional mechanism for learning from irrigation experience exists. In addition, a country's leadership must examine basic issues about the costs and location of food production before specialists are called in to undertake irrigation planning. The policy issues which we feel should be addressed are presented in Table 11, arranged so that the most basic ones are listed first. Indeed, the deteriorating economic situation in many sub-Saharan countries makes a reassessment of investment priorities for agricultural development mandatory. The very unsatisfactory information base on African irrigation means that this study cannot answer all of the questions we have raised, but at least certain clear warnings emerge in regard to why Africa's irrigation performance has been largely unsatisfactory to date.

TABLE 11

KEY IRRIGATION POLICY QUESTIONS

A.	Food Policy
	Consumption trends. Which staples? Produce at home or buy from abroad? What fluctuations tolerable? Pricing policy? What urban/rural subsidies?
B.	Balance between Irrigated versus Rainfed Farming
	Comparative costs of production by zone. What import content in production? Comparative transport costs. What technical opportunities for each? What role in supporting population intensification? What complementarities?
C.	What Kinds of Irrigation
	Large-scale versus small-scale, formal versus nonformal. Full versus partial, total versus supplemental. Authority managed versus locally managed. Supply and conveyance options.
D.	What Crops
	Present yields, irrigated versus non-irrigated. Cost/price trends, internal and external. Available technical packages, input implications. Foreign exchange implications. Food security implications. Integration between enterprises.
E.	Where, When and With Whom
	Phases in development. Location of projects. Acquisition of right? Infrastructural costs. Cost recovery mechanisms. Is settlement included? Sources of staff, expertise. Supervisory structures. Farmer participation.

Source: Adapted from Moris, Thom and Norman (1984), Prospects for Small-Scale Irrigation Development in the Sahel, p. 3.

CHAPTER TWO

HYDROLOGICAL ENVIRONMENTS

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Introduction

The objective of this chapter is to review the climatic resources, surface water resources, groundwater development, and research needs of the continent of Africa for irrigation development. Because of the complexity of African rivers, and the important traditional agricultural systems they support, the "river basin" approach of many development agencies seems inappropriate. What is emphasized is the distinctiveness of a number of different environments within the basins. While they may appear to need similar technological solutions, their problems and prospects are actually very different.

Climatic Resources

Literature Review

A great deal is known about the characteristics of African weather, even if we are still uncertain of the overall atmospheric mechanisms that control it. Griffiths (1972) provides a comprehensive overview of climatic characterisitcs, their cases and links to agricultural production in the various regions of Africa. Thompson (1965) has compiled an atlas of all basic climatic data. In addition, we now have many compilations of basic averages of rainfall, temperature, sunshine duration, and potential evapotranspiration (for example, East African Meteorological Department [1981]; Meteorological Office [1983]; Pearce and Smith [1984]; Thornthwaite [1962]; and van Wambeke [1982]).

Among more general texts Nieuwolt (1977) gives an excellent summary of current meteorological knowledge of tropical climatology and provides a good description of the atmospheric features influencing African weather systems, especially the West African monsoon. Other useful general texts include World Meteorological Organization (1976); Jackson (1977); and Ayoade (1983). Texts concentrating specifically on West African and Sahelian countries include Davy (1974, 1976); and Ojo (1977).

Griffiths (1972) discusses the climates of Africa in relation to his own zonations, based on a synthesis of climate classifications developed by Köppen and Thornthwaite--classifications which are still in general use because of their simplicity. Köppen's classification, which was essentially based on vegetation, was developed by Strahler to show vegetation regions under key weather systems (Barry and Chorley, 1976). This classification has been useful in identifying areas that could be considered to have similar regions of climatic variability and fluctuations.

With increased interest in agricultural development, several new classifications have emerged looking at agroclimatic zones. These have been used in several ways--to define areas of similar problems; to see the possibilities for new crops and to identify similar regions between which it could be possible to transfer local varieties. The impetus to find new genetic material for pasture improvement has been influential in a lot of agroclimatic classification research. Good summaries of current trends can be found in ICRISAT (1979, 1980).

Zoning to look at the agroclimatic potential for new crops began with the innovative but complicated work of Papadakis (1975), but the main system now being developed on a worldwide basis is the Agro-ecological Zones approach of FAO (1978). This develops a technique of matching water balance, temperature, and day length requirements, soils and levels of input, to examine the feasibility of certain staple rainfed foodstuffs. This approach has also been used to develop a regional atlas for West Africa (Kowal and Knabe, 1972).

The droughts of recent years have also been a source of interest, as have been the disruption and famine in societies no longer able to survive droughts. Pearce (1981) presents a set of papers looking at climatological techniques for assessing drought risk. Joyce (1977) provides a bibliography on socioeconomic aspects of drought and famine.

Climate, Climatic Change and Agriculture

A full review of the links between climate and agriculture is beyond the scope of this review. Good general reviews exist in Ruthenberg (1990) and Webster and Wilson (1980). Gallais and Sidikou (1978), Pelissier and Diarra (1978) and Sautter and Mondjannagni (1978) give more insight in the detailed social development that takes place in these environments under different economic and demographic stresses. We would like instead to emphasize three points:

- The relationship between climate and staple foodstuffs;
- The need to understand adaptation to climatic variability in subsistence production, and the problems created when food security systems break down; and
- That rainfall alone is often not a key environmental control of when and where crops are grown. Most soil zones are a key habitat for the production of many foodstuffs within the diet, and often, planting dates may be influenced by photoperiod influences, or the need to harvest during a dry period.

The prevailing wisdom of many climatologists is that the climate of Africa has not changed substantially within this century or recent centuries, although there have certainly been wetter phases within this century. This has been established for desert areas (Bowden et al., 1981; Rasoon, 1984), for North Africa (Shaw, 1981) and for Central and Southern Africa (Nicholson, 1981). The most immediate risks of real climatic change may in fact come from industrial pollution, especially levels of carbon dioxide in the atmosphere (Schware and Kellogg, 1982).

Grove (1983) asserts that a study of the last 200 years of climate in African countries probably does not give us a representative series of data. However, a key feature to understand is the tendency of persistence of wetter or drier conditions over several years. Much research is now taking place on the way small shifts in atmospheric features like the meteorological equator can change rainfall patterns, which in turn encourage vegetational changes and albedo changes, which cause the shifts to stabilize for a period. This gives an option of using either atmospheric features of representative surface features as a "drought indicator" for certain areas (Butzer, 1971).

Thus, where we have instability in food production, and populations now settled in land that is marginal for crop production, we need to see this is in relation to economic and political disruption of traditional food producing systems, or forces keeping population densities above the carrying capacity of the land. A good collection of relevant case studies is given in Prothero (1972).

Climatic Data Analysis

Working from the premise that climate has not changed significantly, three main areas of current research will be discussed. The first is the general problem of collecting representative spatial and temporal data series to use for monitoring rainfall variability. The second is appreciation of the range of environmental variables that can influence definition of agroecological zones and growing periods. The third is improving the calculation of crop water requirements.

The statistical reliability of point or areal estimates of time series of rainfall measurements has long been a topic of concern for climatologists and hydrologists. In tropical rainfall areas, difficulties of maintaining adequate density of rain gauge networks are compounded by the areas "spottiness" of the convective rainstorms which bring precipitation. Most areal assessment techniques still depend on either estimates from Theissen polygon techniques or from regression formulae which link areal rainfall to a number of relief and climatic features. Good overviews of these techniques can be found in World Meteorological Organization (1972), UNESCO (1973), and Rodda (1971).

The extent to which time series of data is seen as a problem depends on the analyst. In most areas of Africa we have very short periods of rainfall records, but Nicholson (1981) documents many sources of qualitative data that can be used to extend these data, and obtain a measure of the range of extremes. However, in the data sets of most semiarid rainfall areas, we not only have to consider extremes of high and low rainfall, but also the tendency to missing dry years in the record.

The whole question of how to analyze rainfall in relation to "risks" to agricultural production is very important. Manning (1956) first developed the idea of considering what likelihood of rainfall failure small farmer production would be adjusted to. He considered that a small farmer would always cultivate a staple foodstuff that survived in most years. He chose to use a rainfall total which a farmer would experience 19 years in 20, i.e., only fail once in his economic lifetime. Small farmers might gamble and plant other groups requiring more rainfall than this, and larger farmers would be certain to gamble with crops requiring higher rainfall, if the profits received could be invested to tide over a year of rainfall failure.

This is a very crude perception of farmer adjustment to risk of crop failure. Most farmers have strategies that enable them to survive one year of failure. The key problem is several years in succession of drought, especially if the intervening spell of good years is short. In the past traditional systems had mechanisms of surviving spells of bad weather, which were recognized as part of the climatic risk, but these mechanisms have largely broken down under economic change (Moris, 1974).

The problem for the analyst dealing with a short period of records not extended by qualitative records is to reconstruct information on these spells. It is particularly crucial if new cropping practices are being encouraged. One article dealing with the problem is Riise (1971)--just one of the excellent series of analytical papers put out by the Bureau of Resource Assessment and Land Use Planning (BRALUP) in Tanzania. Riise's paper deals specifically with the problems of data series begun in the 1960s, which was known to be a wetter period over much of Africa (Nicholson, 1981), and also copes with missing data in the series. Riise does not attempt to develop any abstract theoretical statistical techniques, but simply uses a running-mean smoothing technique to look at periodic fluctuations at stations with both short and long periods of data. He then extrapolates the probabilities of runs of dry periods from the longer time series. Riise shows that there is no climatic change, but cautions against using short time data records from the 1960s. In many African countries the lower rainfall of the 1970s may have helped develop a statistical time series more representative of the climatic variability. However, correlation studies between stations of long and short periods of data is a useful technique, especially for the problems of identifying runs of dry years.

In certain areas it may be feasible to identify a rainfall site or water body whose fluctuations are representative of climatic fluctuations over a wide area. The long records of fluctuations of the levels of Lake Victoria have been used in the reconstruction of Tanzanian climates (Morth, 1967). Butzer (1971) investigates climatic fluctuations over Lake Rudolf, Ethiopia, whose shape makes level fluctuations from rainfall variation conspicuous. He suggests that fluctuations monitored here could be representative of variability over other areas of the northern Rift Valley and the Ethiopian Nile catchment.

Recent progress in the definition of agroecological zones has given us a much wider appreciation of the prospects for rainfall agricultural production in Africa (Higgens et al., 1981). Before the mid-1970s our appreciation of the growing season was made mainly through comparisons of evapotranspiration and rainall, looking at ratios of these phenomena after criteria used to define the onset of the rains. A good summary of these older empirical techniques is given by Jackson (1977) and by Gerbier in Pearce (1981). While these techniques still form the main core of analytical studies, refinements in environmental assessment are being made as more data becomes available (ICRISAT, 1979). The inclusion of temperature and daylight information has helped considerably in helping understand why crops--or certain varieties of crops--thrive better in certain areas, or why farmers plant when they do. Information on humidity and waterlogging has helped in understanding desirable harvest periods, and vulnerability to pest attack (Dancott and Hall, 1979). Many of these features are relevant for irrigation development also. Irrigation may provide water for a dry period, but it is also important to understand day length and temperature regimes of the dry period in selecting a second crop.

Calculations of crop water requirements still also depend heavily upon the traditional models of measurement and calculation. While some areas have sufficient meteorological data to enable the Penman calculation to be used, many areas are still dependent on the cruder Thornthwaite formula (Van Wambeke, 1982) or a diversity of equipment, which are not always easy to compare. Ojo (1977) notes that the Piche evaporimeter is still the main measurement technique in West Africa, whose relationship with the class 'A' pan is often unpredictable. Some ex-British sites still use the sunken square Symons pan. Where data are scarce, the prevailing wisdom is to use pan, Thornthwaite or Blaney-Criddle calculations to calculate potential evaporation (Doorenbos and Pruitt, 1977; Legoupil, 1972).

Although we now have evidence that frequent water applications that keep soil near field capacity is an important influence on yields (Farah, 1983; Hutcheon et al., 1973; Lassoudière, 1978; Omar and Aziz, 1983; Tawadros, 1982), most irrigation schemes do now allow for this regular frequent irrigation, and are designed to apply water at intervals which optimize the number of irrigators using water against any crop yield reductions produced by water stress. Doorenbos and Kassam (1979) have devised a technique for assessing potential yield reduction caused by limited soil moisture availability. The actual amount of water in the soil is most frequently calculated by simply abstracting potential evapotranspiration from available soil moisture (FAO, 1978).

On smaller schemes most irrigation schedules are still worked out from evaporation pan data (Charoy, 1978; Jadin and Snoeck, 1982). Most African sites simply do not have the detailed soil moisture information required for more detailed studies. It is only very occasionally that one finds reference to the availability of a neutron probe (Langelier, 1980), a lysimeter or sufficient soil moisture data for computer modeling (Prashar, 1981). For a survey of some of the problems in calculating appropriate crop water requirements, see Vincent (1980b) and Doorenbos and Pruitt (1977).

Climate and Rivers

As discussed in the subsequent section, most African river basins show a very complex relationship with the climate of the areas they drain. Balek (1977) discusses how the hydrological regimes of water bodies in Africa are controlled by three main groups of features:

- Inputs of water--primarily rainfall, but also baseflow from groundwater;

- Physiographic characteristics of the catchment area; and

- Vegetation.

The difficulties of runoff analysis are compounded by the fact that many African drainage systems are affected by several climatic regimes. However, some of the key problems in monitoring hydrological regimes stem not from difficulties in understanding the effects of topography and vegetation. Balek (1977) devotes an entire chapter to the role of vegetation in African hydrology because of its importance.

The long time scale over which most African drainage systems have developed has resulted in vast, complex low-gradient systems, where interference in one part of the catchment has unpredictable effects on runoff in other sections. Slight changes in the pattern of rainfall can result in large changes in the direction of runoff and which river system benefits from it (Debenham, 1948). The intervening effects of terrain and vegetation mean that the hydrological regimes of the larger rivers only respond slowly to rainfall inputs. Ledger (1969) gives a good description on the complexity of fluctuations in runoff of West African rivers, and in his 1961 article tries to study the effects of vegetation changes on runoff in the Rima Basin, Nigeria. For many African rivers the empirical rainfall-runoff studies which typify much of Western hydrology are inapplicable.

Rodier (1963, 1964) gives an excellent study of the regimes of tropical African rivers. He develops a classification system linked to climatic zones for "smaller" rivers or tributaries where the majority of the catchment is under one climatic zone. This classification shows the differences in the shape of the annual hydrograph that can be anticipated under different climatic regimes, in terms of the magnitude and number of flood peaks, and duration of flow. Within each hydrological regime, however, he distinguishes the hydrographs of small and large streams in order to show the effect of vegetation and flood plain storage in reducing and delaying flood peaks, and extending the duration of river flow. However, Rodier (1964), like Balek (1977) and Ledger (1969), puts the flow characteristics of major rivers like the Niger, the Congo, the Zambezi and the Nile in individual, unique categories.

In the next section reference is made to the few works that exist on modeling relationships between rainfall and runoff for African rivers. We prefer to emphasize, however, that the relationship should not be simplified. A great deal more geographical research is needed before one can really understand the relationships between rainfall inputs and river outputs of African drainage basins.

Surface Water Resources

The Relevance of the River Basin Concept In Africa

A review of African hydrological environments means discussion of some of the most unique and difficult hydrological monitoring problems of the world. While Africa contains some of the largest rivers, lakes, deltas and swamps of the world, paradoxically the availability of water per unit area is the lowest in the world (United Nations, 1977). However, as Scudder (1980) points out, it is precisely this paradox which emphasizes the importance of rivers and lake basins, with their associated floodplains and swamps, for African populations, especially in the dry savanna regions. The major drainage systems of Africa can be easily distinguished, but it is vital to appreciate the diversity of hydrological environments within them, and their interrelationships (Figure 3). There are 15 main drainage systems in Africa (Balek, 1977), some of them draining enormous areas, and geomorphologically they are very different from the smaller, younger rivers of the temperate world. It is easy to regard the smaller rivers and tributaries as similar in nature to western rivers, and amenable to the same resource management concepts, but they are not, for two fundamental reasons.

The ancient eroded river basins of Africa, with their shallow gradients, are not only involved in the distribution of water, but also the distribution of sediment (Faniran and Jeje, 1983). All the natural African hydrological environments, especially the floodplains and swamps, are means for the river to adjust its load and energy to the gradient. Conventional ideas of river regulation to control these rivers which ignore the needs for these mechanisms are likely to have very adverse effects. If they are too alien to the hydraulic regime, river works will fill up, get washed away, or be left stranded.

Secondly, the way people use these drainage systems is very different. To the many people using the diverse hydrological environments of Africa, floods are not the danger--they are the resource, although extreme floods or droughts can cause food stress. Drainage systems in Africa are the basis of many traditional irrigation or recession cultivation societies, and grazing activities. Often only very careful intervention can produce an irrigation system which will produce more food than the traditional system it may have destroyed (Scudder, 1980).

There are two dangerous views of the "potential" of African water resources to support irrigation development that need to be corrected. The first is the idea that flood water is "wasted" water (Heindl, 1974). Flood waters actually form the basis of many key food production and high population density areas of the continent.

The second misconception for Africa is that it is the water alone that controls irrigation potential, i.e., that all that is necessary is to be able to coordinate the water technically. It is water, in combination with good soils and people, that creates potential. As is shown later, however, it is often pedological and social data that are weakest in irrigation survey.

The hydrological literature is littered with surveys of "irrigation potential" assessed primarily on water availability, with no real economic presentation of their practicality. Thus, we have the example for Zambia given by Edwards and Vincent (1981). Zambia is seen to have a potential irrigable area anywhere between one and ten million hectares, of which 150,000 hectares are developable at reasonable cost. The irrigated area project for food needs is only 80,000 hectares, the majority of which is wheat or cash crops whose production is considered beyond the scope of small farmers. There is only a requirement of 8,000 hectares that could be easily produced by small farmers, and there is pressure that even that small acreage should be cultivated by larger farmers because of the ease of marketing.

The river basin concept of demarcating an interrelated system is absolutely right when it helps us to organize the international cooperation necessary for research and development of Africa's many international rivers and lakes (United Nations, 1966, 1977; Platon, 1981). However, the Western concept of assessing a river basin as a means to assess the entire amount of available water that should be apportioned out for the most "essential" uses is likely to have disastrous consequences for many African rivers. Control methods to make "wasted" water available may not only end up citing regulation works completely out of keeping with the geomorphological requirements of the catchment. The price of storing the "wasted" water may be disruption of the few remaining stable and dynamic food producing areas.

We wish, therefore, to keep the idea of the river basin as an overall planning unit, but to stress the diversity of environments within the river basin whose dynamics the planner must stay aware of. River regulation and drainage may be necessary for power and food supplies, but these should be designed with much greater awareness of the adverse effects they can have.

Scudder (1980) outlines how these schemes could be designed with much greater sympathy for downstream users, without enormous loss of power generation and water, and much more attention given to promoting the advantages of improved grazing and fishing that will result upstream. Far too few African dams are multipurpose. We need to include the concept of irrigation more often, and think of irrigation in terms of downstream traditional uses as much as for new schemes. Both the food and supply situation, and the geomorphological complexity of African rivers, gives a strong case for keeping the traditional diversity of hydrological environments that exist, and examining their potential for intensification. Even small irrigation projects take seven to ten years to attain reasonable production levels (Boodhoo, 1981). Most African countries could not cope with the further breakdown of food supplies that might result from implementing a project unlikely to yield the equivalent food production for seven to ten years--except, of course, through further indebtedness (Adams, 1981).

Thus, in the next section, a classification of hydrological environments is proposed. In subsequent sections the key hydrological features which control these environments are described, which must be recognized in data collection and understanding their traditional uses. The results of current attempts to intensify them are also reported.

Classification of Hydrological Environments

The droughts of recent years, combined with the fundamental importance of rainfall-runoff relationships in Western hydrological methodology, has led many workers to emphasize research on water inputs, but in fact, most of the key problems in modeling African hydrological regimes comes from our lack of understanding of the last two features.

A full review of the way geology and geomorphology influences the inland waters of Africa is beyond the scope of this chapter, but a good summary can be found in Beadle (1974). Three points are important. The first is the extreme age of rocks and catchments over large areas of West and Central Africa, features which not only influence the shallowness of flow gradients but are also responsible for the inherently low fertility of many African soils, and often of river sediments. The marine transgressions of various geological epochs, which inundated the depressed areas of the ancient shield, left sediments over most of North Africa, parts of Guinea and Senegal, Cameroon, Angola, Somalia and much of the eastern part of Central and Southern Africa, and have been crucial in influencing groundwater availability. Outside these areas, however, river systems have been evolving over 600 million years. The lack of definitive relief features is an important influence on the development of flood plains and swamps.

Mountain building has only influenced the northeast and southern tip of the continent, and the only real significant feature is the faulting, uplifting, associated subsidence and volcanic activity linked with the Great Rift Valley, which influences hydrology from Ethiopia to Zambia, and where lakes are a key feature of the hydrology. The patterns of uplift and subsidence and vast periods of geological time have helped to create other important influences, especially the number of rivers flowing into inland depressions, with either no outlet or restricted outlets to the seas. Here we can include the Chad, Kalahari, Djouf, Congo and Sudan basins (Figure 4).

Finally, pluvials and glacial periods have caused fluctuations in the long history of the sedimentation of these great basins and lakes, in floodplain sediments and deltas. These zones are not only important for water spreading, but are often key zones for groundwater recharge.

To illustrate the diversity of surface water environments that can occur within one river basin, ideas from Balek (1977), Rodier (1964) and Debenham (1952) have been combined to provide a classification which is linked with rainfall, vegetation and physiographic features, but which is also linked to existing human use and development possibilities. This is shown in Table 12.

In subsequent sections we discuss:

- Rivers and floodplains;
- Emphemeral streams and pans;
- Lakes, lakeside marshes and inland deltas;
- West coast environments and deltas;
- Swamps; and
- Dambos.

Bibliographies of Water Resources Data and Surveys

A number of bibliographies and data tables exist for the hydrology of Africa. Van der Leeden (1975) gives a good summary of resources by country throughout Africa, ORSTOM (1966, 1969) and Dubreuil (1972) give information for Francophone countries and Davy et al., (1976) gives information for Sahelian countries. UNESCO (1969, 1974) gives information on major African gauging stations and selected discharge characteristics. Information on hydrological surveys funded by the Food and Agriculture Organization (FAO) can be obtained through their annual bibliography--the FAO Current Documentation Series. The list of FAO reports is extensive and is not included in the bibliography, as the reader can find topics and countries of interest easily through this annual document. Gischler (1979) summarizes the water resources of North Africa, and Balek (1977) provides a key book for the study of tropical hydrology.

Hydrometric Methods and Surveys

A full discussion of advances in hydrological techniques is beyond the scope of this chapter, so a brief, general summary of available literature and advances is made. Then, for each hydrological environment discussed a representative survey or document to which the reader can refer is suggested.

The importance of understanding why water behaves as it does in African river basins is emphasized, as well as simply looking at the total water resources that can be mobilized. The difficulties in collecting data on vegetation and geomorphology may force us to use rainfall-runoff relationships, but there should be more research promoted on the rainfall-sediment-vegetation-runoff links. In practice, most

TABLE 12

DERIVATION OF HYDROLOGICAL ENVIRONMENTS

Climate	Vegetation	Physiographic Influences	Hydrological Environments
Perennially Well-Watered Regions	Rainforest	Internal Drainage System	Swamps Lakes Rivers and Floodplains
		Drainage to Sea	Rivers and Floodplains Wet Coastal Environments
Seasonally Well-Watered Regions	Savanna	Perennial Drainage	Rivers and Floodplains Inland Deltas
		Intermittent Drainage	Dambos
	Mediterranean		Rivers and Floodplains
Perennially Ill-Watered Regions	Desert and Semi-desert		Empheral Streams and Pans

recent documentation still emphasizes the earlier approach. There are now many more regionally specific rainfall-runoff equations to plan with than ten years ago, but there is little in the way of new ideas for modeling.

Literature on hydrometric surveys in developing countries is now becoming more extensive. The World Meteorological Organization (1972) is an excellent overview of techniques and approaches used in Africa. USAID (1977) and Taylor (1971) summarize measurement technologies that have been particularly useful, while UNESCO (1973) deals specifically with techniques useful to assess runoff characteristics in areas with inadequate data. Two special reports focusing on data collection in arid areas are the International Association of Scientific Hydrology (1979) and Jones (1981).

The basic problems emphasized in the collection of weather data are:

- Physical difficulties in measuring riverflow and sediment data on rivers with great variation in flow, and where high flows spread over floodplains can only be very crudely measured by recording levels;

- The limited number of measurement points on which to base work;

- Limited time series of data; and

- Non-existence of extensive quality data.

Barrett and Martin (1981) give a good discussion of the potential of satellite data in water resource assessment, which could make a contribution to flow monitoring, if countries can bear the cost of what is still an expensive and constantly developing technology (National Academy of Science, 1977).

Key techniques for the regionalization of known information on flow regimes still rely heavily on developing envelop curves around rainfall-runoff relationships (or with river levels). Key techniques for extending time series still rely on extrapolating probability series, or the generation of synthetic data, although Nicholson (1981) emphasizes strongly the potential of qualitative, local, historical information to extend understanding. Studies on sediment load still rely on making limited surveys and linking these with other known features of the flow duration curve.

There are constant complaints about the restrictions that limited flow data--either on low flows or floods--puts on adequate design. We do not agree with this view. We feel that statistical techniques are adequate enough now to construct valuable working information. The problem is much more what designers <u>fail</u> to do with the data collected.

Even where designers can calculate extremes, they rarely use them in design, because they make a scheme too expensive. In virtually every scheme we have analyzed, statistical risk levels have been fixed by scheme economics, e.g., construction cost or maximization of irrigated area, and have nothing to do with the risks experienced by the farmer. Vincent (1980) discusses an irrigation scheme designed against a failure of adequate water of one year in five, and later the project in the Rana River (Appel, 1982) is discussed, where major embankments are being constructed against a flood return period of only 50 years.

Problems with Irrigation Surveys and Implementation

Several workers have investigated reasons for the gap between potential and realized benefits on irrigation schemes--for example, Carruthers (1978); Jurriens et al. (1984); Horst (1983); and Tiffen (1983). One key technical area has been emphasized on improved calculations of water requirements and losses in the distribution of water, to ensure that water gets to the farmer (Jurriens et al. 1984) and that more flexible access is available to farmers (Horst 1983, Tiffen 1985). Vincent (1980) shows the problems that resulted from extraordinarily high efficiencies expected of farmers--factors required to maximize the area irrigable rather than distribute scarce water. Problems of access to water were compounded by the expectation that farmers would undertake night irrigation, and the large number of farmers sharing a water channel.

However, some of the worst technical problems are now seen as stemming from poor soil survey assessment. We have many examples of soils being wrongly classified and proving to be saline (Adams, 1981) or unsuited to the use specified (Savonnet, 1983). However, much worse is the problem of the schemes implemented where the majority of soils are known to be in marginal categories and have difficulties in management. Failure to execute leveling requirements (Adams, 1981) or adequate drainage installations (Azim Abul-Ata, 1977) in order to cut development costs are more common causes of salinization than poor water use by farmers.

The typical range of measurements for an irrigability classification are given in FAO (1979), Mitchell (1976) and Robochev and Samarets (1981). However, Dent and Aitken (1983) is sharply critical of the way that most soil survey data presents information in a useless way. He thinks that soil surveys may have become a ritual recording of limited information that is all too rarely transformed into management guidelines. Very often limited resources mean a survey based on survey features with limited field sampling.

Dent also points out several important features which are difficult for soil surveys to locate--including impeding interfaces at depth, and the presence of certain chemicals. Very little is understood about the behavior and potential of waterlogged soils before they are drained.

This poor initial survey before farmers are settled in areas can be compounded by limited research on crop yields on various soils, or on field trials to establish optimum water application techniques and likely efficencies. FAO (1973) provides an example of the discovery of limited soil knowledge in an area being proposed for irrigation. Only the most fertile soils had been studied extensively. Vincent (1980) provides an an example where field trials for irrigation techniques have been made, but they are adapted to levels of mechanization and labor availability that the farmer cannot achieve.

A scheme with a high incidence of poorly drained and saline soils is likely to present particular problems. Carruthers (1983) emphasizes the way drainage investigations are often inadequate, or not carried out because of the cost. Egypt provides excellent examples. Azim Abul-Ata (1977) describes the way a deliberate decision was taken not to install drainage works before irrigation started (actually, before releases from the Aswan Dam began would be a more correct view) because of the cost. Soil deterioration in previously fertile and stable traditional basin irrigation areas was immediate. Drainage is now a priority, but the disruption has been considerable.

We reiterate the point that we do not think the methodology for data collection is useless--it is the way in which it is used. The frequent problem of reconnaissance, pilot surveys and actual development being done by different groups often exacerbates this problem.

The real problem is the way irrigation surveys always try to maximize potential, in the hope of further work. How many irrigation surveys have said firmly there is no potential, as opposed to judging realities with economic possibilities or detached studies of inputs and outputs? Carruthers (1978) makes some good comments on the unreal perceptions of economics. The problems mentioned come from the insistence of trying to introduce the maximum area immediately, instead of developing a project in stages, only developing further areas when initial areas are shown to work. Some key hydraulic structures may have to be installed with reference to the maximum desirable area, but the vast majority of construction and excavation work could be spread over a much longer time periods. Engineers and governments need to be aware of the alternatives to the "all systems go" approach.

To end this section, there is one other key technical problem--the disruption to farmers of major land use changes introduced through irrigation. Often land leveling, drainage and canal excavation work interrupt cropping for three to four years, yet governments rarely take responsibility for this problem. Engineers comment on the delays caused by farmers who refuse to stop cultivating land; this is hardly surprising if compensation is not paid immediately. Dinham and Hines (1983) note the way work on the Kano project in Nigeria forced many farmers to mortgage their lands to banks or urban interests, so they _de facto_ became tenant farmers. On other schemes this problem has caused violence to erupt, with government forces killing protesting farmers, (the Bakolori Scheme, Nigeria, for example).

The emphasis now should switch to improving the interpretation of survey data for its management implications, including many of the flexible design options discussed by Horst (1983), Tiffen (1983) and Jurriens et al. (1984). There should be more sensitive phasing of project introduction and much greater protection of the rights of small farmers involved in the areas affected by schemes.

Rivers and Floodplains

Mention has been made of the complexity of the 15 main river basins of Africa, and this chapter has stressed the need for a conceptualization based on rivers as geomorphic agents and agricultural foci, rather than just water. The vast quantities of water and sediment carried by most African rivers have necessitated the natural development of vast floodplains. Virtually all major floodplain zones are also important areas of groundwater recharge.

The easiest way to discuss the diversity of African rivers is to consider the way they present development potential (or problems) in relation to groups of people. Three catchment types will be discussed:

- River draining hydrologically complex catchment with low population densities overall, either because of disease, remoteness or agricultural limitations, but where pockets of high rural and urban population densities exist, e.g., the Zambezi, the Volta, the Congo (complex, remote);

- Large rivers draining hydrologically complex catchments but with quite high rural population densities along much of the river, as well as major urban centers, e.g., the Niger (complex, populous); and

- Smaller rivers or tributaries following more conventional geomorphic profiles and recognizable drainage nets, with high rural populations along the rivers, e.g., the Senegal, the Tana, the Sabi, the Hadejia, the Cunene and tributaries like the Sokoto and the Kano rivers (apparently conventional, populous).

All of these have been submitted to the resource management concept of assessing water potential, then budgeting this out to various needs. It is the failure to see the existing agricultural water use as a "need," however, which has caused such extensive disruption by projects in the last two categories of river basins.

Indigenous use of rivers in Africa is widespread in all categories of rivers. Flood recession agriculture is widespread throughout Africa, where vegetables or cereals are grown on moist soil zones exposed by receding floods. Small gardens are irrigated by lifting water, and in regularly inundated zones rice has been domesticated indigenously. In some sites irrigation furrows were developed, although these were more widely developed by white settler farmers. These uses are documented in Azim Abul-Ata (1977), Beyer (1980), Kjekshus (1977), Mbawala (1980), Scudder (1980), Upton (1969) and Vincent (1981). Floodplains also support important grazing land.

Several of these irrigation societies have intensified spontaneously, as market opportunities for vegetables has increased (Marchal, 1970), Deitchman and Boulet (1979) and Vincent (1981), or new varieties of rice introduced (Waterworth, 1964, 1967). However, there has been very limited effort to expand the activities of these crops by aid agencies, usually because of the efforts required for collection and marketing of surplus. Vincent (1981) discusses the development of vegetable production which took place while a State collection system was in operation in Mumbwa district, Zambia. Waterworth (1967) investigated the introduction of new floating rice varieties for inundated floodplain zones--which locals did not cultivate despite a wide range of local varieties adapted to all other habitats. Interestingly, Waterworth found it impossible to select a variety that could cope with the variability of inundation depth and local photoperiod influences. His work is useful, however, in discussing some analyses for floodplain inundation prediction from gauging records.

To look at the effects of development in the three categories of rivers, one needs to distinguish developments for power and water supply, which invariably means dams, from developments to intensify agriculture. These may mean dams, but one can also look at prospects for smaller scale lift schemes and irrigation furrows, and at intensification of existing irrigation which may need little new technology.

In the first category--"complex-remote" catchments--there have been few interventions, except for power development. The approach here has been simple--to see all upstream resources of a feasible dam site as available for regulation. The impact of some of these dams has been considerable, since they show no concern at all for agriculture. Chambers (1970) notes the extraordinary resettlement experience of the Volta Lake. Scudder (1980) discusses the disruption of the Kariba Dam, noting that by regulating the flow of the Zambezi it caused the destruction of a recessional agriculture society with the densest population in Africa. Conversely, planners have made no attempt to assist the greatly improved grazing that now exists in the immediate catchment of the Kariba Dam, which could be some substitute for destroyed food resources.

In the second category--"complex-populous" river systems--dams or barrages for power have again been the main reason for intervention, although the existence of established agricultural societies downstream has meant that more attention to agriculture is essential.

The Aswan High Dam of Egypt is the best example of this, where it is the dam releases which have converted a stable seasonal irrigation system into a permanent system currently unable to cope with the attendant waterlogging and salinization (Azim Abul-Ata, 1977). Zikri and El-Sawaby (1979) also discuss the way river regulation has reduced the fertility of soils previously regularly inundated by silt. It is the existence of permanently inundated channels which has caused the substantial increase in bilharzia (Amin, 1977). Daget (1977) discusses the general effects of pesticides on prospects for fish production. Shaheen (1983) and Temarak (1983) discuss the increased pest infestations following intensification of agriculture. Most disturbing of all, Worthington (1977) discusses the general deterioration of the ecosystem along the Nile, with permanent irrigation bringing rats much more strongly into the domestic habitat than previously.

The barrages for the Gezira and Office du Niger did have irrigation more specifically as a project focus, although their location in less populated areas of the catchment has made them a vehicle for extensive settlement programs. The settlers on the enormous schemes have suffered from identical problems as the indigenous fedayeen of the Nile (de Wilde, 1967; Barnett, 1975, 1979). Despite the 50 years of technical progress between the construction of the Gezira/Office du Niger projects and the Aswan Dam, the impacts have been almost exactly the same. Once again, it is not really lack of knowledge which is the problem, it is the failure of planners to consider paying for the features which would give a farmer easy, flexible production. Perhaps it is the belief, also, that whatever the effects of a project, an appropriate technical solution must exist. If the solution does not work, one can always blame the farmers (Azim Abul-Ata, 1977).

However, it is in the third category, the "apparently conventional-populous" rivers, that the greatest intervention of aid is observed. This is partly because we are dealing with rivers of smaller flow, which are much more easily controlled, but it is also because these rivers characterized much of the areas of West and Central Africa recently hit by drought, and thus have been the focus of great aid effort (Stryker and Gotsh, 1982). Thus, it is in these rivers that the really negative impact of the "water resource mobilization approach" of western hydrology is seen.

In the debate about the developments of these rivers we are usually dealing with technical solutions. There are some locations where small-scale technologies alone are the focus of development (Gillet, 1973; Ardayfio-Schandorf, 1982). These options include irrigation furrows, small earth dams and pump lift schemes, which may be individual or communal. The environmental impacts of such schemes are small, and the hydrological data required for their design quite simple. Their problems have come either from technology (Cruz, 1981; and Keller et al., 1982), organization of settlers (Clayton, 1978; Weir, 1978), or the labor constraints of proposed crop production (Vincent, 1981).

More commonly, however, the solution has been to promote dam schemes which may not only supply water for new irrigation developments (see the summary for Nigeria by Ogutoyinbo, 1970), but can also regulate river flow and thereby make small pump-lift schemes installed along the river valleys easier to operate, and support a bigger settlement. It sounds simple, until the loss of production from existing societies are considered.

The key point is the effect regulation of flow has on the water regime on downstream floodplains which are in use for irrigated or recessional cropping. Evidence on this comes not only from the large number of dams being built for urban water supply (Olofin, 1982), but also from those built for irrigation (Adams, 1983). Olofin compares the effects of a number of small dams in upper streams on tributaries of the Kano River (which are actually nearer the many urban settlements) and the impact of the much bigger Tiga Dam. Water storage at the smaller dams did not greatly affect the amount of water reaching the main river, but caused considerable disruption to agricultural activity. Releases from the Tiga Dam have converted a wide seasonal alluvial channel with a regular lateral shift to a more stable perennial channel with a well-defined new floodplain (fadama), which Olofin considers larger and more fertile than the dispersed alluvial patches of the old floodplain, and says that the new floodplain is actively grazed.

Olofin notes this as a fortuitous result, since there was no investigation of optimum flow releases to achieve a desired geomorphological result. However, it is not actually known whether the new fadama is supporting the same families, a larger number of animals or is still providing any food crops. These doubts are confirmed by Adams (1983) on the effect of the Bakolori Dam on downstream floodplain villages of the Sokoto River, Nigeria.

One further problem is that dams are not an easy solution on the sandy soils of floodplains, and many of the existing dams show very high seepage levels. Even siting of smaller projects faces this problem. Bajsarowicz and Welton (1979) discuss an investigation for the construction of a storage reservoir by blocking an abandoned flood channel. The geotechnical exploration revealed underlying sands which would require costly seepage control measures so that development options focused strongly on groundwater use. There is a considerable transition to the use of groundwater sources where seepage ensures a regular recharge.

These effects happen throughout Africa, but the disruption is most starkly observed in the countries where the uptake of aid, or the availability of oil capital, has meant the use of foreign consultants still using the inappropriate concepts of water resource mobilization described. While it is known the same problems are happening on the Tana River in Kenya, and many Nigerian rivers, it is the Senegal River which has generated the most literature.

Fears about the impact of the Senegal Project are give in Adams (1981), Fauchon (1981), Bessis (1982), and Scudder (1980). The fundamental question is the real feasibility of grafting an entirely new set of crops onto what will eventually be a new pattern of settlements, with farmers very dependent on a government parastatal responsible for supply of inputs. The scheme for the Senegal River is not purely concerned with agricultural performance; it is also concerned about easy extraction of bauxite and iron from the interior. The scheme has two dams--the Manantali on an upper tributary, which regulates the flow of water in the main river but also provides power for the mining area, and the Diama upstream of the delta. It also envisages the digging of a navigable channel between the two dams. The project is not about the production of traditional crops like millet or local varieties of rice--it is actually concerned with producing rice and wheat for the towns. Scudder (1980) doubts whether the new area irrigated will produce an equal amount of food as the habitat it has disrupted, even after the long implementation period is completed.

Bessis (1982) and Adams (1981) both comment on the difficulties small farmers have in producing enough to eat on the plots of land allocated in settlement schemes. Requirements to produce wheat, rice and tomatoes for market have interfered with the role of women in producing supplementary foodstuffs for a balanced diet. River regulation will halve the supply of fish, the main source of protein. Even if the projects produce enough for the towns, the settlers may suffer poorer nutrition and become further marginalized. Scudder (1980) describes the traditional yields obtained for maize, rice and fish in parts of the Senegal River and doubts if the new projects will yield this equivalent even if the projects stabilize after seven to ten years. The food deficit during the gap is unthinkable.

One further problem beyond the types of cropping dates being introduced is that of the settlements themselves. Both Adams and Bessis doubt whether they can be grafted onto the villages or smaller schemes that have developed over the last half century. In light of settlement experience from Zambia [(Weir, 1978) and Clayton (1978)], this is also doubted. The failure of the government to involve local people in planning, and reduction of independence, in cropping has caused considerable animosity. Clearly the new scheme will produce food, but can it be afforded? Bessis thinks that the oil requirements for pumping stations will put up a staggering petroleum bill.

In conclusion, a note of caution is sounded in the rapid resource mobilization of African rivers. Much greater investigation of aspects of food security is needed--the current and potential production of existing production should be clearly stated against the yields of irrigated production, and careful analysis made of the sources of foodstuffs in the interim period where construction and development of projects interrupts supplies.

Dams for power and water supply are necessary, but the need to protect the interests of downstream users have to be more carefully understood. Where river regulation is encouraging the development of floodplains by groundwater pumps, greater concern over which farmers are obtaining the pumps and the land rights is needed. There is a far greater case for developing existing rainfed agriculture in the settled floodplains than aid projects have considered to date.

Ephemeral Streams and Pans

Intermittent runoff occurs over much of arid and semiarid Africa. The drainage that occurs from heavy storms with rainfall close to or in excess of soil infiltration capacity, so there is a rapid, flash runoff response to rainfall. This drainage is different from dambos, where the drainage is from interflow and soil saturation. Good summaries of the characteristics of arid zone hydrology and data collection techniques are given in Jones (1981) and by the International Association of Scientific

Hydrology (1979).

In some areas ephemeral streams follow old drainage lines developed in wetter periods and have clay beds which make them useful for agriculture despite low rainfall--examples of these are the dallols of North and West Africa. These can be important for food crops, or to produce pasture or forage crops for grazing. More typically, however, there are wadis or dry stream courses. Some drain naturally to the sea, as with some of the Namibian systems (Stengel, 1964). Others focus into pans. Because of the evaporation that takes place over these pans, there is a buildup of saline deposits which in turn contaminate the water that collects in them (Robertson, 1950). Many of these pans have important links with groundwater recharge (UNESCO, 1980). The main technical developments for ephemeral streams are the building of small dams or excavation of cisterns to catch runoff. Examples of traditional "hafirs" to store water come from the Sudan and several North African countries. The construction of temporary dams with trees and earth is also known in several parts of tropical Africa (UNDP, 1968). However, these runoff catchments are now being developed much more systematically (Intermediate Technology Group, 1969), either to provide water for cattle (Fortmann and Roe, 1980) or for crop and pasture irrigation (Wenner, 1970; Upton, 1969; Pascon, 1983).

Prospects for crop production or intensive livestock production depend on the reliability of annual runoff and transport links. Where these are reasonable, as in parts of North Africa, specialization and early production can help settlers to corner part of the market (Pascon, 1983). However, elsewhere they can prove uneconomic for crop production against the cost of production (Upton, 1969).

Where a natural pan is the focus of development, water quality may restrict activities into grazing. Ephemeral streams carry a high sediment load which can make dams difficult to develop. One solution is to develop a "runoff" plot on a laterite surface, or even a surface covered with concrete. These tanks and cisterns have been the basis for some very small (micro-irrigation) but successful developments in Tunisia and Botswana (Intermediate Technology Group, 1969). Where settlement and marketing possibilities exist, the development of ephemeral streams may be worth considering.

Lakes, Lakeside Marshes and Inland Deltas

Natural lakes are an important feature in the hydrology of East and Central Africa, being found from Ethiopia to Mozambique in association with the Rift Valley. However, one needs also to mention the internal drainage of Lake Chad, the lakes associated with the old "inland delta" of the Niger, and Lake Aloatra in Madagascar. Africa has 15 lakes with an area of over 10,000 km^2, many of which form the boundary of more than one country.

In addition, there are now a number of manmade lakes resulting from dams for hydroelectric power, e.g., Lake Volta, Lake Kariba, Lake Kossou, Lake Kainji and Lake Nasser. Problems with the impact of these projects have already been discusssed in the section on hydrometric methods and surveys. Many of these natural lakes already have traditional rice growing societies or societies using the wetlands under recessional cultivation. Most of these societies produce rice, except for the drier zones where rainfed farming alrady produces a food staple. Thus, at Lake Zwai, Ethiopia, small irrigated plots produced vegetables and used recessional cultivation for maize, which is also the main rainfed crop (Makin, 1976). Lakeside marshes have been distinguished from swamps precisely because they are so often used for cultivation under traditional practices, and they have attracted attention from developers because further small-scale reclamation is seen to be economically feasible. Most irrigation investigations have concentrated on lakes where there is already irrigation, and have concentrated either on intensifying production or reclaiming further land by controlling lake levels and constructing embankments.

The traditional rice producing lake societies are quite well documented. They have usually developed dynamically under population pressure, and their fine apreciation of water control and appropriate crop varieties has attracted attention. Bouquet (1983) describes the rice cultivation around Lake Chad, Gallais and Sidikou (1978) the Inland Delta of the Niger, and Ramamonjisoa (1983) the rice cultivation in reclaimed marshes around Lake Aloatra, Madagascar. In the vegetable production around Lake Zwai, more limited cultivation seemed to reflect fewer local markets and the incidence of marginal soils if reclamation was extended further--precisely the two problems which weakened the final prospects for the scheme.

The report by Gallais and Sidikou (1978) outlines the adaptation of traditional rice production to two sets of risk--the arrival of the rains on the one hand, with sufficient but not excess water. Many land facets are distinguished according to soil fertility, which is very low away from flooded lands. They comment on the extraordinary variety of rice strains used locally for different planting dates and sites, and that resist different types of pests. What is particularly interesting is that village fields are constantly changed by a collective rotation, which is adjusted to what villagers believe is a four to seven year cycle in maximum and minimum flood levels. This cyclic variation and persistence over several years of high or low flows is noted independently by Waterworth (1964). Villagers cultivate a variety of other flood crops as a security against flood failure, and the system is accustomed to shifting over wide areas.

Intensifiction has been pursued both through attempts to introduce new high yielding varieties and to introduce floating rice varieties. However, it appears to be difficult to select a floating rice variety which can incorporate a variable inundation date with photoperiodic influences (Waterworth, 1967). The problem with the high yielding varieties is that villagers find the specific weedings and watering of these crops difficult to crop, given the demands on their time from other food crops. Equally important, however, has been the poor performance of the local rice mill in collecting surplus yields of rice. This is partly due to difficulties in processing such a wide variety of seed types, but poor management has also been influential.

Further development in these lands is by lake-level control and embankments which require careful siting (Tricart, 1960). These schemes have formed the basis for further developments on Lake Faguibine (Niger Inland Delta), Lake Victoria (Gibb, 1956) and the Lake Zwai project. Apart from the costs, the projects may well face difficult soil conditions once the waterlogged sediments are drained. This will be discussed further in the section on deltas. The most detrimental feature, however, is the increase in schistosomiasis once lake levels have been stabilized (Goll, 1982).

The new polders developed for lakes, like those developed for deltas, may seem attractive because of the potential surplus of one single rice variety produced, which can be easily milled. In practice, however, it has proved difficult for new settlers or estate workers to organize themselves under the external management involved to maintain the works. Perhaps the combined effects of easy marketing and milling, full control and minimum costs are the real reason why state farms are being considered. However, there may be very real soil and disease risk problems in their development.

More effort could go into intensifying the traditional systems. Sustained research into better genotypes, combined with harder attempts to collect the surplus rice, are needed. There could also be experimentation with the extension of village size polders, with settlers organized in traditional patterns, without the emphasis on large polders which will produce only one rice variety.

Techniques and survey methods for lake investigation can be found in Makin (1976) and Kramer and Stegemann (1966). Several attempts have been made to monitor the water balance of lakes and their fluctuations in water level (Morth, 1976; De Baulny, 1970). These often involve models correlating rainfall over the entire basin or parts of it, direct rainfall on the lake, evapotranspiration and lake levels.

Wet Coastal Environments and Deltas

Traditional irrigation societies and development prospects need careful distinction between these two environments, although the technical solutions may appear to be the same, i.e., the need for land reclamation and flood control. The driving force for investigation of deltas, lagoons and tidal creeks is their potential to produce rice on a large scale. Although in some stretches of the West African coast, irrigation is used for the intensification of oil palm.

Some of the best examples of traditional irrigation societies exist in wet coastal environments along the coasts of Senegambia, Guinea-Bissau and Guinea-Conakry (Pelissier and Diarra, 1978; and Oosterbahn, 1982), a zone characterized by lowlands sinking under coastal muds interwoven by a dense network of streams, deeply penetrated by estuaries and surrounded by forests. By bunding tidal creeks against the sea, dry land is created that can be cleared and used for cultivation, and in this stretch of coastline rice is the staple crop. Considerable attention has focused on intensifying production in this area. It is essential to realize that the main source of water for the traditional agriculture is derived from rainfall. Equally important is the nature of cultivation within the embanked areas, with rice seedlings planted out on ridges. Oosterbahn (1982) explains how this ridging offers a crucial control over salinity and also over the deterioration of the acid sulphate soils which typify this coastal area.

Similar environments in Ghana, within the Volta delta area, but not part of the active delta, support the intensive vegetable production of the Ewe (Grove et al., 1983). Interestingly, in the slightly drier environment of this zone the staple food is yams; hence, the selection of this lucrative cash crop.

Other areas along the coast between Liberia and Benin, also dependent on root crops as staple foodstuffs, show little evidence of traditional irrigation development, but there has been government interest in increasing production of oil palm under irrigated plantations from lagoon reclamation (Dissou, 1983). Other examples available include traditional rice growing on similar areas within (but not in the active part of) the Tana River delta in Kenya (Appel and Vierhout, 1982), and also the coast of Madagascar (Ramamonjisoa, 1983).

Intensification of these environments can take place in a number of ways (Horst, 1983). Attempts can be made to intensify existing production, or can be extended on a small-scale by small new local embankments (Oosterbahn, 1982), or new large-scale polders can be attempted in delta areas previously uncultivated. Large-scale polders can be cultivated either through resettlement or run as state farms. Examples of extensive delta development schemes in existence or planned are the Senegal River (Adams, 1981), the Nile (Diab, 1982), and the Tana (Appel and Vierhout, 1982).

Pelissier and Diarra (1978) give a good summary of the problems faced in simple intensification of production of rice. It is actually difficult to improve on the large varieties of rice adjusted to the wide range of habitats, although any suitable new strains introduced have been adopted immediately. The polders have sluices to control water level and are carefully monitored. However, extraction of any surplus is subject to the same marketing constraints that have been discussed for the Niger system (Gallais and Sidikou, 1978). Ironically, this system has begun to break down under the combined effects of outmigration (particularly for cheap labor in France in the 1960s) and the inroads of other cash crops like oil palm.

Oosterbahn (1982) makes a study of the difficulties of the next option--new small-scale polders. One problem is the difficulty of organizing land use for areas given to new settlers, or combining villages where labor constraints are already extensive. Many of the older embanked areas are cultivated as a unit by one village. In his study for the introduction of an oil palm plantation in a newly reclaimed lagoon Dissou (1983) reaches the same conclusion. While there were still some serious technical problems which alienated settlers from the management, the settlers were also virtually the equivalent of estate laborers and felt they were not paid enough for the work undertaken and yields produced.

The crucial difficulty in extending embanked polders in these areas is, however, the soil complexity, especially the presence of acid sulphate soils. These are waterlogged sediments containing iron and aluminum sulphates in reduced forms which oxidize rapidly to yield iron and aluminum ions and sulphuric acid and, not surprisingly, extremely acid soils. Oosterbahn notes that there are currently no easy field identification techniques for acid sulphate soils. He speculates that the reasonable pH of the old polders is probably due to careful improvement over time by drainage control, or that local cultivators have their own methods for recognizing potential acid zones. Any rapid development of new embankments on acid sulphate soils will have disastrous consequences, not only because of the difficulties soil acidity will present to cultivation for several years, but also the acid that will be released into other waters by drainage.

Like Oosterbahn (1982) and Horst (1982), it is agreed that the best solution is to attempt intensification of production in existing small polders by further research that might suggest small water engineering improvements, but above all by infrastructural improvements to improve marketing and social facilities that might stem outmigration. However, pressure for import substitution of staple foodstuffs for the urban population has led to the launching of extensive reclamation of the Senegal, Tana and Nile deltas.

This large-scale polderization has some crucial implications that the small schemes show up. The first is the uncertainty of soil fertility after it is drained, so that accurate soil survey is difficult. Small traditional polders utilize rainfall, which leaches out salts. However, the large polder schemes will be producing two crops a year by using river water to flood the fields, so salnity risks increase, especially if land leveling is poor. The ridging techniques used for rice production in traditional systems offers an additional protection against salinity and poor water control that cannot be constructed by mechanized techniques. These points should be borne in mind when actual experiences in the Senegal delta are reviewed (Adams, 1981). Above all, however, there is the extraordinary cost of this reclamation work.

A comparison of proposed work for the Tana delta (Appel and Vierhout, 1982) with actual experiences in the Senegal delta (Adams, 1978) enables us to compare technical expectations and planning with the socioeconomic implications. The Tana scheme envisages complete flood protection and adequate internal drainage for 10,000 hectares, which will be irrigated by river water conveyed from a diversion weir. The polder area is actually scheduled as a state farm, envisaging the employment of estate workers and outgrowers. The capital cost in 1982 for flood protection and drainage works alone were estimated at over $5,000 per hectare, and almost $7,000 when storage, milling and compound facilities are added. Apart from repayments of this capital, annual running costs of $970 per hectare.

At top yields, which are probably unlikely on a highly mechanized state farm, production per hectare will only be equivalent in value to about $1,500 a year. Any increase in capital and running costs, or low yields, is starting to make the project look perilously uneconomic. While this project should produce 50 percent of Kenya's rice requirement, it seems that this project will have to be subsidized, presumably, a cut in government expenditure in welfare spending to subsidize further the urban food supply.

This plan should be seen in the light of Senegalese experience. Adams (1981) concentrates on the difficulties faced by local population and settlers not only in relating to management, but coping with the indebtedness superimposed on them. Large-scale rice cultivation has been considered for the delta for 125 years. Adams notes the unmitigated financial disaster of the first attempt to develop 10,000 hectares in the 1950s, although this area did produce about 10 percent of Senengal's rice requirement. In the 1960s an ambitious attempt to develop 30,000 hectares was launched, although it was discovered subsequently that 19,000 hectares were too saline to be used, and poor leveling on remaining areas gave poor water control and very low yields. In 1968 crop failure due to lack of river water led the authorities to install pumps, while at the same time halting all further settlement and project development.

The Senegal delta project in theory has small settler farmers rather than estate workers, but the scale of intervention by management has made them very little different in practice, with requirements of mechanization and insistence on fertilizer use leading to substantial indebtedness. Indeed, it now appears that, as in Kenya, state farms are being considered, as they offer the widest margin in covering costs and repaying loans, since labor need only be paid by the working day.

Adams (1981) links the delta developments with river regulation projects upstream to show that the plan is for a vast area increasingly under double cropping to produce rice and wheat, phasing out traditional staples of millet and sorghum. While on the one hand the potential food output might be commendable, river regulation will halve the yearly catch of fish, the main source of protein, and will also increase the incidence of malaria, river blindness, and bilhazia. Adams' data for the costs of projects and the scale of local indebtedness to the delta authority gives disturbing implications for persistent indebtedness at both the national and local level.

Returning now to the technical design of the Tana scheme in the light of this study. The first problem is the existence of a considerable area of imperfectly drained and saline soils. The second question is the reliability of estimates of expected river flows, and the stability and geomorphic effects of works to control these flows. Appel tells us that the protection works, already extremely expensive, are designed against floods with a return flood period of 50 years. Even fairly ordinary urban floodworks are designed against a flood return period of 100 years. Simple probability analysis tells us that there is a 13 percent chance of a flood of this or greater magnitude occurring within the seven year implementation period of the project. There is a 22 percent chance of such an event occurring in the next 20 years. These calculations were not based on local gauge levels. Levels from a station upstream were adapted using the Muskingham flood routing procedure, something that may not be that reliable in a delta stream.

This methodology is not criticized, since it is the best available with limited data. The flood risk level is criticized, taken in the light of the uncertainty of the data. It appears as a classic example of the economics for cost benefit analysis controlling the scheme designed. A 50-year flood protection scheme is all that can be afforded--it is not what the scheme requires. The article tells us nothing about the frequency of low flows, or the effects on flows of any further regulation of the Tana River, but the SAED experience tells us that this is an essential component to study. So too would be a search for the tendency to spells of high and low discharges in the river regime.

Finally, essential in any study is a genuine attempt to model the geomorphological effect of any diversion work to lead river flows onto a plot of land, and of spillways to carry excess flood water. River training works are notorious for their unpredictable effects on siltation and scour, and diversion works are notorious for the extensive seepage and localized waterlogging created. As important for salinity control are the real difficulties in controlling water distribution across large fields. The cooperation of small farmers will probably achieve better yields.

The Nile Delta is not mentioned extensively here because it is an essentially unique environment relevant to North Africa experience. However, experiences there have many parallels with the Senegal experience. The Nile Delta is a large-scale reclamation project, made feasible by water releases from the Aswan Dam, with adverse soil conditions compounded by poor quality water (Schulze and Ridder, 1984). Diab (1982) gives a summary of the technical problems and the high costs. Articles by Dayem, et al. (1978) give practical insight into the very real difficultis of controlling salinity in these areas, as well as discussing hydraulic models developed to design the optimum drainage network.

Swamps

Definitions of swamps are often quite specific to countries (UNESCO, 1975). Balek (1977) notes that no classification of African swamps has been made. He makes a review of existing definitions in order to describe the uniqueness of the African swamp environment, as distinct from that of seasonably inundated floodplains and dambos. In this review dambos are distinguished from swamps because they appear to have different hydrological origins which must be understood in their development.

Swamps are distinguished from seasonally inundated floodplains primarily on the degree of marshiness and unique vegetation regimes--features which give them a very different role in traditional irrigation systems. The distinction also shows up differences in technical development difficulties, as swamps will require a high degree of impoldering and drainage which, as Horst (1982) points out, can be extremely expensive and carry many adverse social consequences. Waterlogged areas may seem as amenable to the same technical solutions, but certain environmental differences, together with the differences in societies that use these wetlands, give us very different development problems.

The frequent general use of the word "floodplains" in technical literature overlooks this point. A good example of this is the Kafue flats which, although de Groot and Marchand (1982) refer to them as a floodplain, we consider them a swamp. The scale of development costs and completely different intensity of current usage makes them very different from, for example, the floodplains of the Hadejia River in Nigeria (Brouwer, 1982).

Within the various types of marshy areas one finds swamps linked to both rivers and lakes (Gibb and Partners, 1956). We have chosen to discuss lakeside swamps and marshes together with lake water bodies themselves, as these are integrated areas both in their traditional uses and development prospects.

Thus, in this section the perennial swamps fed by river water are discussed. They are frequently linked to topographic depressions, from which outflow may or may not occur regularly, and act as natural reservoirs and erosion regulators. It is the pattern of inflow and outflow which makes swamps unique, as outflow is usually only a tiny fraction of inflow, with enormous evapotranspiration losses. Within this general pattern of behavior, each swamp is also unique.

Individual swamps vary in their ratio of inflow to outflow, their groundwater recharge and their over-year storage. For example, there is little over-year storage in the Okovango because of the huge evaporation over a water sheet less than 2 meters deep. However, water may take several years to move through the deeper and slower-moving Kafue and Sudd. There are few published studies of models of African swamps. Balek (1977) reports some studies on water flow through swamps that use the Muskingham flood routing technique. He also reports the difficulties in measuring evaporation because of the unique interplay of moist soil, vegetation and water surfaces which changes anyway across the year. Most evapotranspiration losses are estimated indirectly after comparing inflow and outflow. Sutcliffe (1976) thinks that hydrological models of swamps can only be qualitative.

Africa has 17 major swamps covering areas greater than 2,500 km^2. The best known of these are the Sudd of the Sudan, the Middle Congo (Zaire), the Okovango (Botswana) and the Kafue and Lukanga flats of

Zambia.

Swamps often have unique ecologies, and aquatic vegetation plays an important role in the water budget through transpiration. Vegetation was originally considered to influence the flow of water through a swamp (Debenham, 1948), but this is no longer considered true (Botswana Society, 1976). It is vegetation, however, together with disease hazards, which are key determinants of traditional use of swamps.

An excellent summary of the previously balanced use of the Kafue flats is given by de Groot and Marchand (1982). They go on to suggest that improved livestock, fishing and tourism may be much better development options than embankments and drainage. Impoldering is not only dubious economically, it will leave soils which will be difficult to work. It will require a plantation cultivation system because of technical management needs and the low population density of Zambia. This will destroy the actvities of the existing population and create a dependent labor force. Reclamation will also alter the outflow in the Kafue River downstream of the faults and eventually the Zambezi, although the agricultural impact of this is not discussed. While there has been a great deal of discussion about the "potential" of the Kafue Basin, in fact the whole reclamation plan has developed because of hydroelectric potential, not because of the real interests of food production.

The same motives and the same problems behind discussion of the potential of the Okovango can be seen. The Okovango is even more complex, as siesmic movements are now known to affect the balance of the inflow and outflow, as much as rainfall variability. Depending on the rainfall and the area flooded, water from the Okovango can send water to the Zambezi via the Chobe, or itself receive water from the Chobe (Botswana Society, 1976; Debenham, 1948).

Pilot investigations in the Okovango also show soil development problems. The speed of water movement in the Okovango, which is also characterized by shallow depth of water, is such that the bedload is considerable, but suspended load is rare (Botswana Society, 1976). Thus, drainage would expose large areas of sandy soils of low fertility and high risks of wind erosion. Experiments with sprinkler irrigation--hardly a small farmer technology, but necessary because of the sandy soil, were defeated by the low soil fertility. One site where alluvial soils did exist, however, was too isolated to make large-scale developments feasible unless communications were improved.

Drainage of the "Sudd" swamp in Sudan is likewise associated with power development. Incoming water from one of the inflowing rivers, the White Nile, is diverted into the Jonglei Canal before entering the swamp and being conveyed to the Aswan High Dam. The Sudd waters are required to balance the enormous evapotranspiration losses over the dam, and thus maintain the flow of water for power generation. Despite the enormous areas of the swamp, the water will meet only 50 percent of the evaporation losses from the dam (Fauchon, 1981). The Jonglei scheme has received a variable press. Scudder (1980) discusses the impact on the Dinka and Nuer pastoralists who graze animals around the fringes of the swamp supplies by the White Nile. Fauchon (1981), however, thinks that grazing improvement could occur in areas crossed by the Jonglei Canal, and efforts should be put into promoting this.

Overall, the prospects for major development of swamps are not encouraging. We agree with Horst (1982) that the major need is research on improving existing agricutural economic activities in these areas. Much greater geomorphological understanding is required before impoldering should even be considered as a technical solution. Planners should stop seeing the flooding and evapotranspiration of swamps as a "loss," and see instead the extraordinary wealth of wildlife, grazing potential, and fish that is often a feature of these areas.

Dambos

Dambos are intermittent swamps. By combining several definitions given in Balek (1977), Russell (1971), Debenham (1952) and Telford (1950), dambos can be described as streamless, periodically inundated grassy depressions, usually treeless, and at the head of a drainage system, in a region of dry forest or bush vegetation. While some dambos may not carry water, the water table is usually within a meter of the surface throughout the year.

Dambos are important zones for grazing, vegetable gardens and even rice production in local agricultural systems in Malawi, Zambia, Zimbabwe and Botswana, and have received attention for their potential development for small-scale irrigated production of vegetables and rice (Vincent and Elling, 1981; Telford, 1950). Small-scale lifting of water from hand-dug wells has been used to intensify vegetable production already taking place in moist soil zones and drainage canals, pumps and small earth dams have been installed in wetter dambos to develop them for rice production.

Dambos usually offer significant grazing land and may be the subject of complex rules of access and rights of use (Russell, 1971). They can deteriorate rapidly from overgrazing and from unrestrained cultivation. Prior to any planned intensification, a careful analysis of their often complex soils is required (Telford, 1950). Typical features of the soil are that they are poorly drained, slowly permeable, deep, and strongly acidic (Balek, 1977).

Dambos differ from swamps because of the nature of their recharge. As dambos are a feature of the upper catchment drainage, the rocks are less weathered and more easily saturated by subsurface drainage, although in the inner parts of the dambos weathered deposits may be deeper. Inside the dambos the depth of weathered rock, and hence the storage potential is variable, depending on geomorphological evolution under subsurface drainage, or during wetter times, and usually dambos show an asymmetric pattern of drainage.

Thus, unlike swamps, which are recharged by streams, dambos are recharged by rainfall. Vincent and Elling (1981) point out how a market transition in the wetness of dambos and their uses occurs with the increasing annual rainfall as one moves east-west across Zambia.

Monitoring dambos and their development potential is difficult because of the complex relationship between rainfall, vegetation, and runoff. Infrared aerial photos have assisted in demarcation of the dambo areas. Balek (1977) reports hydrograph studies monitoring the balance of surface and subsurface outflows and notes how vegetation studies can assist in the delineation of moisture zones and their changes across the year. He also reports on attempts to recreate size and shape of dambos with the pattern of runoff, and reports on studies of the interesting pattern of evapotranspiration over dambos areas.

Groundwater

Groundwater Resources

Groundwater development has supported many traditional irrigation systems across North Africa, where its development is still an important focus for developing the arid areas. Over most of tropical Africa there is little development of social systems oriented around groundwater, although hand-dug wells on floodplains and dambos have allowed smallscale development for vegetable production. There are areas, however, where groundwater resources offer prospects for both large- and small-scale projects.

An excellent summary of the groundwater resources of Africa can be found in United Nations (1973, 1977). These works give the geological background to groundwater resources, the yields that can be anticipated from borewells and data collection techniques. Gischler (1979) and Schliephake (1972) give a good overview of groundwater prospects in North Africa, and the Comité Interafricain d'Etudes Hydrauliques (1976) has produced some good working maps of resources for sub-Saharan Africa. Because of the limited development of groundwater for irrigation, most information is found in reports for rural water supply development. Stow, et al., (1976) provides a good bibliography up to the mid-1970s, which can be extended by a literature search in journals such as Groundwater and Journal of Hydrology. Bibliographies by ORSTOM (1966, 1969) give details of French work, and the work by Hopkinson and Beavington (1979) gives groundwater information on British Commonwealth territories. FAO and UNDP have also undertaken geohydrological surveys for development prospects in many areas of Africa (for example, UNDP, 1968).

In the section on the "river basin concept," a brief overview of the geological evolution of the African continent is presented. The core of Africa is still the ancient, pre-Cambrian "Basement" complex of metamorphic schists, gneisses, and quartzites. Where these rocks are exposed, groundwater resources depend on the depth of weathered material and the climatic recharge to them. Faulting by tectonic movements, or buried drainage channels of old rivers, can create favorable resources for development, but yields are usually very low, and will rarely support an irrigated area of more than two hectares. They are not feasible development sites for borewells, but they can be important for supporting small irrigated areas based on hand-dug wells. These can be seen in large parts of West and Central Africa (Vincent, 1978; Vincent and Elling, 1981).

Over the remaining areas of Africa there are quite complex geological cross-sections of sedimentary rocks, created by a series of marine transgressions over much of North Africa and the coastal zones, and/or by riverine deposition over millions of years. In some locations orogenic movements have resulted in volcanic deposits.

The rocks of the complex sedimentary basin that exists over much of North Africa, Mauritania, Chad, and the Congo Basin are generally referred to collectively as the "Continental Intercalaire." In northeast Africa Mountain building and faulting has caused uplift of these rocks. Over old coastal areas like Mauritania, Senegal, Cameroon, Angola, Somalia, Mozambique, and Madagasgar are found the aquifers frequently referred to as the "Continental Terminal," in which clay materials are more common. In central Africa there is no generic term to cover the cross-sections, but important areas are the Katanga, the Karoo, and Kalahari deposits.

Many areas of these pre-Quaternary basins have been covered by riverine and deltaic deposits laid down in the wetter "pluvials" over Africa since the start of the Quarternary period. These have shaped the groundwater matrix of many African deltas, floodplains and deserts, and are often referred to as Plio-Quaternary deposits.

Prospects for dug wells depend on the water table behavior in the uppermost stratum, but borewells may collect yields from several strata. Since many of these strata were laid down in wetter periods, one important concern is whether tapped reserves are currently recharged, or whether they are fossil reserves. Where fossil reserves exist, water quality is also a major concern.

Drilling down through these strata will show a great mixture of limestones, sandstones, and shales which yield water, and they have been widely developed for water supply. However, the higher yields that would make groundwater economic to develop are only found in certain sandstone or very specific limestone strata. While limestone deposits exist in several regions across Africa, it is only where solution channels have developed under the influence of the wet pluvial periods that high yields are obtained. Thus, prospecting for groundwter reserves at depths that could sustain irrigation development is a skilled job.

Borewells have been developed by individual large-scale farmers and utilized subsequently for sprinkler production, but there are few smallholder projects based on them. However, the recent sediments laid down in floodplains and deltas are increasingly seen as a groundwater resource and there are now areas where pumplift systems are developing very quickly.

While national and international assistance has gone in to developing boreholes in North Africa, little interest has been shown in tropical Africa, although there is one example in the Mpongwe Project in Zambia. However, quite a lot of funding for training of geohydrologists has taken place (Heindle, 1974; Berger, 1975), whose skills could be more specifically directed to prospecting water table and artesian aquifers for groundwater irrigation prospects. The key problem, as with surface water, is to encourage the idea that small diffuse programs are equal in importance to major projects.

Groundwater Assessment

An extensive discussion of techniques will not be made here because of the wide range of geohydrology books that exist. Reviews of techniques for Africa exist in United Nations (1960, 1973), Food and Agriculture Organization (1975), Schoeller (1959), the World Meteorological Organization (1972b) and DHV (1979).

Techniques for assessment relevant to African conditions have centered around:

- Remote sensing techniques (Barrett, 1981; Comité Interafricain d'Etudes Hydrauliques, 1976);
- Ground survey of water table conditions in existing wells combined with exploratory borewells used for resistivity survey and pumping tests (Mohammed et al., 1979; Sedwale and Farr, 1980);
- Isotope studies of current and fossil recharge (Foster, 1978); and
- Assessment of the role of floodplain inundation in groundwater recharge (UNESCO, 1980).

Groundwater Development

The best known examples of African groundwater development are the oases of northern Africa. These tap water table conditions created by a variety of geological circumstances through a wide range of techniques, including wells and qanats. An excellent overview of various types of Saharan oases is given by Nesson et al. (1973). However, oases have never been the basis of independent self-contained production systems. Their production, excavation, and maintenance can only be understood in terms of trans-Saharan nomadic groups, who not only used the products but also controlled the slaves who ran them. Oases were as much commercial service centers as suppliers of food. With the breakdown of nomadism, so too has come the breakdown of the economic viability of the oasis (Wilkinson, 1978). Poor water quality has made date production the main product of many oases and limited demand for these, together with the high transport costs, have left most oases as fossil settlements, far removed from favored coastal settlement zones.

Many oases have been further damaged by falling water tables

(Manger, 1981). Collapse of the social systems which excavated and maintained water sources has also been an important influence. Thus, most oases still functioning depend on pumps, access to which has been the subject of many disputes (Fauchon, 1980), as new forms of water distribution may not match old tenure organizations (Nesson et al., 1973).

Attempts to resurrect the agricultural potential of oases have as much to do with political concern to maintain a presence in what are now remote and backward areas as with their real economic potential. Old oases sites are thus now in the same economic category as the many small desert farms developed on the basis of borewells. Depending on water quality, they can supply vegetables and livestock to urban coastal markets if adequate transport is organized. Prospects for sustained settlement and agricultural production in the desert do appear to be linked to the degree of government assistance and control and the ability of settlers to survive the general isolation.

Within the prospects for water table development over the rest of Africa there is a need to distinguish the environment of the large river floodplains and inland lakes from the more generalized prospects across the weathered surfaces of Africa. The main opportunities for water table development do exist only along minor or major drainage lines, and in some areas developments have already been considerable, even if the scale of transported surplus is small. In areas close to rivers or lakes, irrigators will lift water from the river or hand-dug wells, according to the distance of their plots from the water source. Deitchmann-Boulet (1979) gives an interesting account of the irrigators around N'Djamena, Chad and Vincent (1981b) discuss the small producers in the Mumbwa district, Zambia. Dupriez (1979) contains a case study from the Badeguicheri Valley, Niger where sinking of wells for domestic use led to a doubling of irrigated production.

While much of the well irrigation in Africa is still primarily domestic and marketed very locally, irrigated production can develop rapidly where there are good marketing prospects. While some of the existing production is still dependent on hand lifting, which limits the area that can be irrigated, pumps are making a rapid impact. All the papers presented at the Second Fadama Seminar (1984) concern the development of water in floodplain zones by pumps. A paper by Chapman presented at this seminar gives an illustration of a specific program to develop fadamas across northern Nigeria using individual groundwater pumps, a project likely to produce over 50,000 tons of vegetables.

Labor availability and access to technology are the key development issues in promoting equitable development of groundwater. Most small farmers will not take up irrigated production unless they have enough resources to ensure their subsistence production. Thus, many of the families involved in irrigated production are already the established ones. However, farmers performing hand lifting techniques can only irrigate half a hectare or less, although the financial return can be considerable. The real impact on the area irrigated develops with the introduction of pumps (Vincent, 1981b).

The introduction of pumps also introduces the question of who gets the technology. Vincent (1981b) showed that banks were extremely unwilling to extend money to small cultivators for the purchase of pumps, and those cultivators who had pumps were either the larger farmers favored by banks, or those who had got the financial resources together privately to purchase pumps.

The question of who will control access to the landsites favorable for pump development is also important. In India the introduction of pump technology has led to the "buying out" of smaller farmers and tenants to enable a larger area to be cultivated under one pump. As yet there are have been no studies which tell us whether this trend is starting to happen in the floodplains being developed in Africa.

Turning now to borewell development. Across the settler country of Central and Southern Africa there are many examples of individual large farmers (which are now black as well as white) sinking borewells on which to base sprinkler irrigation for wheat, vegetables, and fruit. Occasionally there are examples of small farmers combining together as a cooperative and exploiting political opportunities to obtain a borehole.

The promotion of settlements based on high-yielding borewells are rare in Africa, and where they have developed, there have been few encouraging prospects for the small farmers. The Mpongwe Project of Zambia serves as a good example. Here, high-yielding limestones mean the possibility of developing a considerable area. While the project zone is close to Copperbelt markets and could have been the focus of a smallholder settlement with good marketing prospects, the decision has been made that the project should contribute to the wheat needs of the towns, and thus appropriate sprinkler systems have been designed. These high infrastructural costs have necessitated choice of a cash crop as the second crop, which also has to be appropriate to soil fertility needs, so soybeans have been selected (Landell Mills, 1979).

The high mechanization requirements mean that smallholders are not considered at all for the project and land is being distributed in 40-hectare blocks to interested settlers, who are mainly wealthy retiring civil servants from the towns. However, uncertainties about real profitability of the proposed cropping routine because of high capital and running costs has meant hesitation from even these settlers. Production of vegetables could be an equally lucrative crop, but if it develops it will interfere with the prospects of promoting vegetable production by smallholders. The consultants involved in the project, Landell Mills, have pointed out many of the technical difficulties and uncertainties of the project.

In conclusion, there are considerable prospects for groundwater development across Africa, but for small farmers these have so far been restricted to the use of water table sources for vegetable production. There is borewell potential, but so far this has been kept as the preserve of larger farmers and has been more linked with the promotion of irrigated cereals.

Prospects for the future could include increasing the use of water table sources near river and lake areas, although care is required to ensure that smaller farmers get fair access. Key issues include the way technology is promoted and marketing facilities are organized.

Training of hydrogeologists to help in the location of such small developments is also needed. Technical personnel need to be encouraged to see small programs as "projects" that are just as important as the larger schemes that usually get their attention.

The prospects for development of borewells for small farmers need much more attention. It is hoped that borewells will not remain in the preserve of large farmers, but could also be used through the organization of cooperatives or as the basis of settlement schemes. There is strong evidence that in areas close to sound markets farmers are prepared to form a cooperative that not only manages the water but pays for part or all of the cost. It is hoped that borewells will be considered for other food crops as well as cereal crops.

Research Needs

Recent droughts and famines in Africa have emphasized the issue of food security in Africa. On the one hand there is a diffuse rural community that needs better nutrition, but that must also produce the food requirements for the other group, the urban consumer, which is given much greater attention. It is a paradox that the food staples being promoted by aid agencies are alien to Africa and can only be developed extensively through irrigation. Like Higgens et al. (1981), we think that rainfed agriculture could produce much more if it systematically attracted the attention that irrigation projects have.

There should be more emphasis on maintaining traditional staples such as urban foodstuffs, especially where it is clear that expansive irrigation projects will require government subsidies which will distort the prospects of expenditure on other aspects of development. Irrigation does have an important role to play, especially for promoting the livestock and vegetable foodstuffs that will improve nutrition. However, much greater attention needs to be paid to the real economics of production, both for the national government and the producer, if irrigation development is not to be synonymous with increased indebtedness.

There is also concern at the interim disruption of important areas of food supply that can be caused by river regulation schemes. Where dams for water supply or power are constructed, their releases should show a greater awareness of existing downstream floodplain producers. Irrigation projects developed by river regulation should show greater sympathy for existing food production patterns in the area being drastically changed by the new organization of access to water.

Like Carruthers (1983), we think there are many issues in the poor technical and economic design of irrigation projects that need more research before a new era of large irrigation schemes is launched. Some of the most crucial are to ensure that possibilities to minimize the disease and salinity hazards are fully considered and costed in the financing of schemes. Better information on soils and their management problems is needed in order to design appropriate crop strategies that will give the small farmer a financial incentive as well as keeping him/her properly fed.

Labor supply and returns to labor remain the strongest influences on how a farmer becomes involved in irrigated rather than rainfed production. Unless mechanization can be overseen by an efficient management at economic costs, it is still not a solution. With the current unreliability of food supplies that can be purchased with cash, it is inevitable that farmers will ensure their subsistence needs first. Better appreciation of the issues of labor supply and the returns to labor, and more recognition of the unreality of the cash economy in many parts of Africa would make a big contribution to improved planning for irrigation schemes.

In this chapter we have tried to stress the diversity of African hydrological environments in which irrigation could be implemented. It is felt that much of the current "river basin" approach gives an oversimplified view of the resources available for irrigation. The ideas of river regulation that it promotes are often out of keeping with the geomorphology of many African drainage systems. Like Horst (1982), we feel failure to recognize this could lead to adverse changes in hydrological environments which could further jeopardize the food supplies of the rural areas.

The diversity of environments and their hydrology so that the real difficulties of mobilizing them can be understood has been stressed. Most large-scale developments will be extremely expensive to develop and will not be able to run without subsidies. In this respect, therefore, the attention of agencies to the "food security" problem is failing to answer the much larger questions about how African countries can generate more income for themselves, both to subsidize food production or for other development needs. The only answers may lie in fairer prospects for exports and industrialization.

Irrigation does have a contribution to make, both in nutrition and cash crops, if developers make sure that it is a fair alternative for the farmers or estate workers who are in the end responsible for production. Without this no amount of aid for irrigation will alter the food shortages currently experienced in Africa.

CHAPTER THREE

SCHEMES AND SETTINGS

Introduction

The marked differences between Africa's official irrigation projects and its indigenous, traditional systems makes it difficult to analyze the two types within a common framework. As our discussion of small-scale irrigation in chapter six will indicate, official schemes are generally designed and established from scratch, with external assistance. Most have salaried staff and a formal project structure. Whether large or small, their organizational features are very different from the simple arrangements and technologies found where irrigation has evolved spontaneously in response to local needs. This fundamental duality is reinforced by the "top-down," expert planning associated with formal schemes in contrast to locally generated solutions within traditional irrigation. It is also reflected in the tendency of formal schemes to receive advice from engineers and agronomists, while traditional systems are left to be described by sociologists and anthropologists. Size alone is not a useful criterion for distinguishing the two types. While most traditional systems are very small, their aggregate contribution in a given zone may be large, just as some formal projects are also very small in size (though usually quite expensive).

In this chapter, we have accordingly treated the two major types separately. Africa's officially sponsored irrigation schemes are described in the first, where for each country reviewed we have presented one major case outlined at some length. Formal schemes are best seen within a national context, related to each country's approaches to irrigation development and its institutional structures. A brief description of the national context precedes the description of individual schemes. The choice of cases for review has been made to include the major countries where irrigation is important (excluding Somalia, Madagascar, and Southern Africa), and to insure a spectrum of scheme types ranging from small-scale, NGO projects to the very largest national systems. To situate the case study schemes in relation to Africa's other projects, Table 13 overleaf lists the continents' better known formal irrigation systems. References to these schemes found in other chapters frequently employ a shortened designation (e.g., Bakel, Mwea, Gezira, SEMRY), since these particular projects are well-known among African irrigation specialists.

The preponderance of governmentally-assisted projects within Africa's modern irrigation sector also means, however, that much of the documentation needed for describing individual projects and for assessing their performance is not publically available. By far the larger share of project documentation consists either of lending agency reports, notably those of the World Bank and FAC (for Francophone countries) or IFAD, or of commissioned consultancy reported (usually retained by the

TABLE 13

SELECTED AFRICAN IRRIGATION SCHEMES

This listing follows FAO (1986:88-118), amended where feasible by reference to detailed sources. Users should note extreme discrepancies between sources, especially regarding areas planned (M) vs. actually irrigated (A)

Country NAME OF SCHEME Major Sources	When Built	Area (ha) M = maximum A = actual	Crops Irrigated	No. tenants Av. holding	System Description
Mali					
OFFICE DU NIGER Fresson (85), de Wilde (67)	(1932-60s)	56,000 (M) 41,000 (A)	Rice & some sugar-cane (3-5,000 ha)	5,700	Markala dam on R. Niger supplies Sahel & Macina sectors by gravity
OP. RIZ-SEGOU Bingen (85)	(1950s, 72-75)	35,000 (M)	Floating Rice	15,000 2.19 ha	Partial control flooding of diked polders along R. Niger, Bani, Koni
OP. RIZ-MOPTI Binger (85)	(1972-75)	31,000 (M) 26,000 (A)	Floating rice	7,800	Partial control flooding of diked polders along R. Niger
Sudan					
GEZIRA-MANAGIL Barnett (77), El Agraa (86)	(1925-	468,000 Gez. 397,000 Man.	Cotton, groundnuts wheat, sorghuym, vgs.	102,000 (G+M)	Gravity-fed from Sennar Dam on Blue Nile into 2 main sections, G & M
NEW HALFA Sorbo (85), Pearson (80)	(1962-69)	164,000 (M) 70-140,000 (A)	Cotton, groundnuts + sugarcane estate	22,000 6.3 ha	Dam on R. Atbara into gravity-fed surface distribution, 15 fd
RAHAD Benedict (82)	(1973-78)				Pumped from Blue Nile diversion gravity-fed, highly mechanized
KENANA Abdel Rahman (85), Wohlmuth (83)	(1976-80)	34,000 (M)	Sugarcane estate w/ ind. complex	10,000 employees	Pumped water from White Nile, factory at site, continuous production
Senegal					
RICHARD TOLL		7,400	Sugarcane		Joint private/gov. irrigated estate
NIANGA Weiler & Tyner (81), Weiler (79)	(1966-75)	750-2,000 (M) 630 (A)	Rice, 2x per yr. Initially mechanized	599	Pumping from Senegal R., diked polders, run by 36 producer groupings
DAGANA Dumont (85)	(1973-79)	2,400 (M) 1,700 (A)	Rice, initially mechanized		Pumping from Sengal R., reservoir & diked polders, 2 of 3 units used

relevant country firm). For the most part, we have not enjoyed access to either of these two major types of sources in compiling this review. This makes it exceedingly difficult to give accurate and fair accounts of individual schemes, and restricts coverage to those projects which are documented in published literature. Even FAO's specialized reports, of which there are hundreds relating to the technical aspects of individual schemes, are not freely available except in response to specific requests made with official backing. Such restrictions constitute a major obstacle to African countries' being able to learn from each other's experiences. They also insulate lending and implementing agencies from being held accountable for their own mistakes.

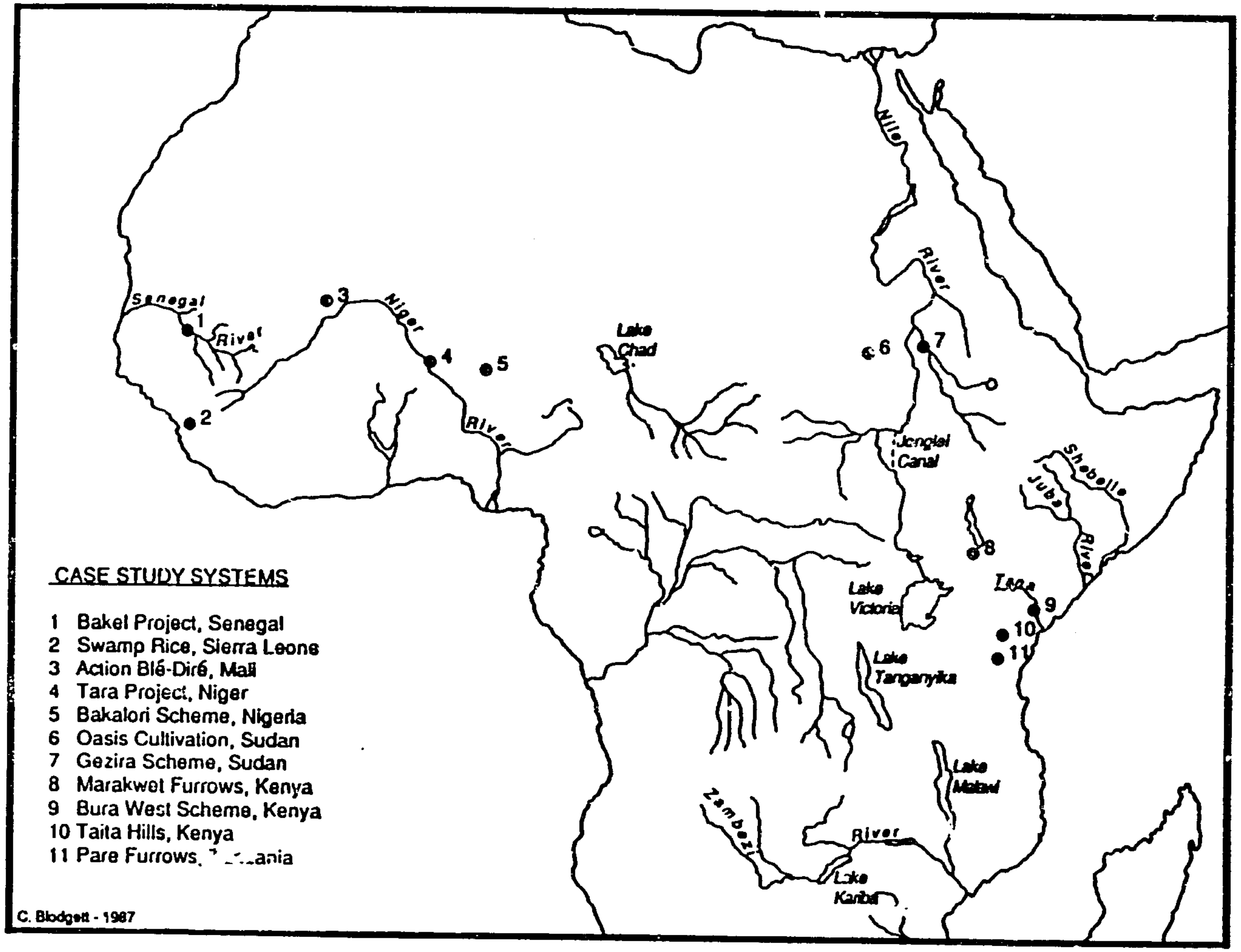
The second part of this chapter describes Africa's traditional irrigation. Indigenous systems are not distinctive to particular countries, but instead occur within certain settings which make small-scale irrigation feasible. Montane furrow irrigation, for example, is found across the highland areas of East Africa, just as "swamp rice" cultivation is found in coastal West Africa. For readers not familiar with African place names, the schemes and systems described in this chapter are located on a map of the continent in Figure 5.

Irrigation Schemes

Senegal

National Background - Like its neighbor, Mali, Senegal spans several agricultural zones, which range from Sahelian conditions (350 mm annual rainfall) in the north to coastal swamps (1,600 mm rainfall) in the south. The terrain is mainly flat, with fossil sand dunes near the coast. Rainfall gradients change in transverse bands, from dry to wet along the north-south axis. Areas along the Senegal River in the northern one-third of the country have only a one- to two-month rainy season (August-September); the central area from Dakar eastwards to Bakel near the Mali border has a three-month rainy season (July-October); the southeast has four months; and the Cassamance region south of the Gambia River has five months (Keller et al., 1982).

The estimated population in 1985 was 6,600,000, spread over a land area of 196,860 km^2 but concentrated towards the western side nearest to Dakar. The country is divided into eight regions and thirty "departments" (equivalent to districts). Senegal was the headquarters of the former French West Africa. It has considerably higher rural population densities and more urbanization (35 percent) than typical for other countries in the Sahel zone. Dakar still contains a number of institutions serving the larger Sahel zone, and one finds influential Senegalese families spread throughout the zone (but especially so in neighboring Mali). The population is quite mobile, being comprised of seven main ethnic groups. Communications by road and rail are relatively good. Over the past decade, the country has been heavily involved with Mali and Mauritania in a joint project (the OMVS) for the development of the Senegal River Valley.



CASE STUDY SYSTEMS
1 Bakel Project, Senegal
2 Swamp Rice, Sierra Leone
3 Action Blé-Diré, Mali
4 Tara Project, Niger
5 Bakalori Scheme, Nigeria
6 Oasis Cultivation, Sudan
7 Gezira Scheme, Sudan
8 Marakwet Furrows, Kenya
9 Bura West Scheme, Kenya
10 Taita Hills, Kenya
11 Pare Furrows,
Senegal River
Niger River
Lake Chad
Nile River
Jonglei Canal
Shebelle
Juba River
Tana
Lake Victoria
Lake Tanganyika
Lake Malawi
Zambezi River
Lake Kariba
C. Blodgett - 1987

FIGURE 5

Despite being a major recipient of external aid, Senegal's economy has been in decline since the mid-1970's. About 50 percent of all export earnings and 40 percent of government revenues are generated from peanut (groundnut) production. About half the nation's cultivated area is given over to this crop, though production is concentrated in the "peanut basin" inland from Dakar. Except in drought years, annual production (1976-82) averaged about 780,000 t, most of it processed locally before export. Millet and sorghum are the main food staples (600,000 t annually), with some maize (43,000 t) having been introduced in the southeast. A modest amount of cotton is also produced in the south. About 65 percent of the nation's annual consumption of sugar (80,000 t) is produced locally (De Vres, 1984, vol. 2, p. 212). About 90,000 t of rice is produced annually (14 percent of all cereal production), of which 80 percent comes from traditional "swamp-rice" varieties grown in the Cassamance (Toure in Buddenhagen and Persley, 1978:341).

The irrigation potential within Senegal occurs around the nation's periphery, either along the Senegal and Falémé Rivers in the north, or in the south along the Cassamance River. While some studies have shown Senegal with a high irrigation potential, e.g., a CILSS estimate of 457,000 ha (1979:76), the FAO estimate of 180,000 ha seems more reasonable, which would indicate that over 50 percent of potential has already been developed (1986:14). Irrigation has taken different form in the three major environments where development projects have been attempted. In the Senegal delta upstream from St. Louis (the former capital), saline intrusion during the season of low flow has hampered crop development (though the delta has also supported a significant local fishing industry). Here projects for crop irrigation involve large investments, and have tended as a consequence towards medium and large-scale perimeters (e.g., the Richard Toll plantation). In contrast, the middle and upper portions of the Senegal River provide an opportunity for numerous small and medium-sized perimeters, utilizing river terraces, old channels, and small swamps. And, finally, the Cassamance area in the extreme south resembles the Gambia River in having mangrove swamps at its mouth, a long distance subject to salt intrusion, and traditional techniques for "swamp-rice" cultivation. Though ambitious plans remain under consideration for the construction of four salt-intrusion barrier dams on the Cassamance, in fact the first generation projects aimed at diking the mangrove swamps were spectacularly unsuccessful. In general, the easier sites for small-scale irrigation in Senegal have already been developed, so that future projects will require larger interventions carrying a higher risk of failure.

Irrigation Institutions

Irrigation development has a long history in Senegal, having been the focus of one of France's early experiments in agricultural colonization, the unsuccessful attempt in the early 1800s to turn the delta region into an irrigated island of prosperity. (Dagana was even designated at one point as the future capital of Senegal.) Between 1821 and 1826, experiments were conducted to discover what crops might be grown in shallow basins under controlled flooding. Mixed results achieved by Richard Toll, the person in charge of the experimental farms, were interpreted favorably and by 1826 6,500 ha had been given out to French settlers in 130 ha units (Miller, 1985:33). Local opposition, agricultural difficulties and problems in water control doomed the project despite an attempt in the 1850s to resurrect it. Nevertheless, the name Richard Toll was bequeathed to what has become Senegal's major, large-scale scheme: a 7,400 ha irrigated sugar estate owned and operated by a private French-Senegalese sugar company, the CSS (Miller, 1985:33).

Senegal's modern involvement with irrigation dates from the early pre-war years, when to counteract growing rice imports MAS (Mission d'aménagement du Sénégal) was formed in 1938. Of the first three perimeters it built, only the one at Guédé (1,000 ha) is still in operation (Miller, 1985:34). In the immediate post-war period it expanded its operations to include large pumping stations near Lake Guiers, as part of Senegal's continuing effort to counteract salt water intrusion during the river's low flow season. OAD (Organization Autonome du Delta) took over responsibility for the delta in the early 1960s, prior to the formation of SAED (Société d'aménagement et d'exploitation des terres du Delta) (Miller, 1985:35). Some of the embankments built to control the river's flooding and to keep out salt water were major structures, one dike being 84 km long. In 1964 when SAED took over, roughly 31,000 ha were protected by dikes on Senegal's left bank, but of this much has since been abandoned (Miller, 1985:35).

SAED originated with the objective of bringing modern irrigation to the delta region, but then gradually extended its influence upriver to the middle and eventually upper basins. It was at first linked to the "animation rurale" concept under the regime of Mamadou Dia (Miller, 1985:37). The government's stated aim was at this time to foster formal cooperatives to give peasants a place in the national economy. These were initiated from above in a highly centralized and authoritarian manner, and they bypassed whatever associations (age groups, etc.) already existed at local levels. In time, the term "cooperative" acquired such negative associations among farmers that SAED and other agencies have renamed them "producer groups" (groupement de producteur), a term applied to water user groups which share an assisted perimeter. However, even at present agencies like the distant and highly bureaucratic OMVS are quick to insist these groupings represent merely "pre-cooperatives," to be replaced by full cooperatives as small-scale perimeters are gradually phased out.

Thus when SAED began working in the delta from 1965 onwards, its approach was distinctly "top-down." As described by Miller who observed its activities in the field:

> [I]t treated the zone as a virgin frontier, settling colonists, displacing local herders, and forcing each family into a tenancy relationship with SAED. Each tenant received inputs on loan from SAED, would be asked to grow rice during the rainy season, and then . . . to reimburse SAED in kind for the materials and services rendered. Debts were so high and productivity so low that this policy encouraged outmigration

rather than reducing it. . . . (Miller, 1985:38-89)

However, it can be said in SAED's defense that it did learn from its own mistakes as its emphasis shifted increasingly to the support of small-scale village controlled perimeters.

SAED's first generation efforts like Nianga and Dagana (Figure 6) drew upon the delta's tradition of large-scale farming, with comparatively large perimeters designed for mechanized production. Prior schemes had been based on the "partial control" concept, whereby the perimeter was provided with external embankments to regularize the river's flood levels. A crop like floating rice would then be sown under rain-fed conditions, but guaranteed the correct levels of water once the river's flood arrived. As indicated below (see "Nianga" and "Dagana" cases), this approach failed on all counts: the mechanized operations proved to be highly inefficient and problematic; peasants had little incentive to contribute the labor needed to keep the scheme operating; and in low rainfall years the flood level was insufficient to insure a crop. The schemes were thus converted to full-control perimeters through the addition of pumps, and SAED changed its own emphasis towards assisting small-scale, non-mechanized perimeters. Weiler and Tyner (1981) argue SAED acted prematurely in abandoning its large-scale approach. The whole rationale for OMVS involvement in sponsoring irrigation is also based on the premise that larger, full-control perimeters will be superior to SAED's subsequent small-scale ones--a conclusion not supported by Senegal's actual experience.

SAED's "second generation" schemes grew out of collaboration with FAO and the World Bank in the Matam area from the early 1970s onwards, where the first three "village irrigation schemes" (or VIS) were located in an experimental adoption of a type already pioneered across the river in Mauritania (at Gorgol). These "middle river" schemes were of necessity smaller than the larger perimeters found in the wider delta. Individually between 6 and 20 ha in size, perimeters were furnished with a float-mounted diesel pump, flexible pipe connection to convey the water up over the banks onto river terrace lands ("fonde" soils), a cement junction box to facilitate water distribution, and surveyed and bunded plots of one-third hectare per family. The first pumps were provided on a grant basis, but it was found that they were not maintained and problems arose over replacing them. SAED's contribution was to supply the pumps and equipment, organize land preparation, operate any heavy equipment required, and supervise farmers and village masons in building the simple distribution system. It was hoped that families could realize about 0.9 tons of maize and 1.7 tons of paddy from double cycle cropping of their plots, and from the half they would sell could repay SAED's charges and the operating costs incurred by their perimeter committee. To insure repayment, they could only market paddy through SAED at the government's low official prices; farmers' associations held individual contracts to insure their compliance. Inputs were also supplied through SAED alone, and charged against each season's loan obligations.

Up to 1977, when SAED entered into external loan negotiations to

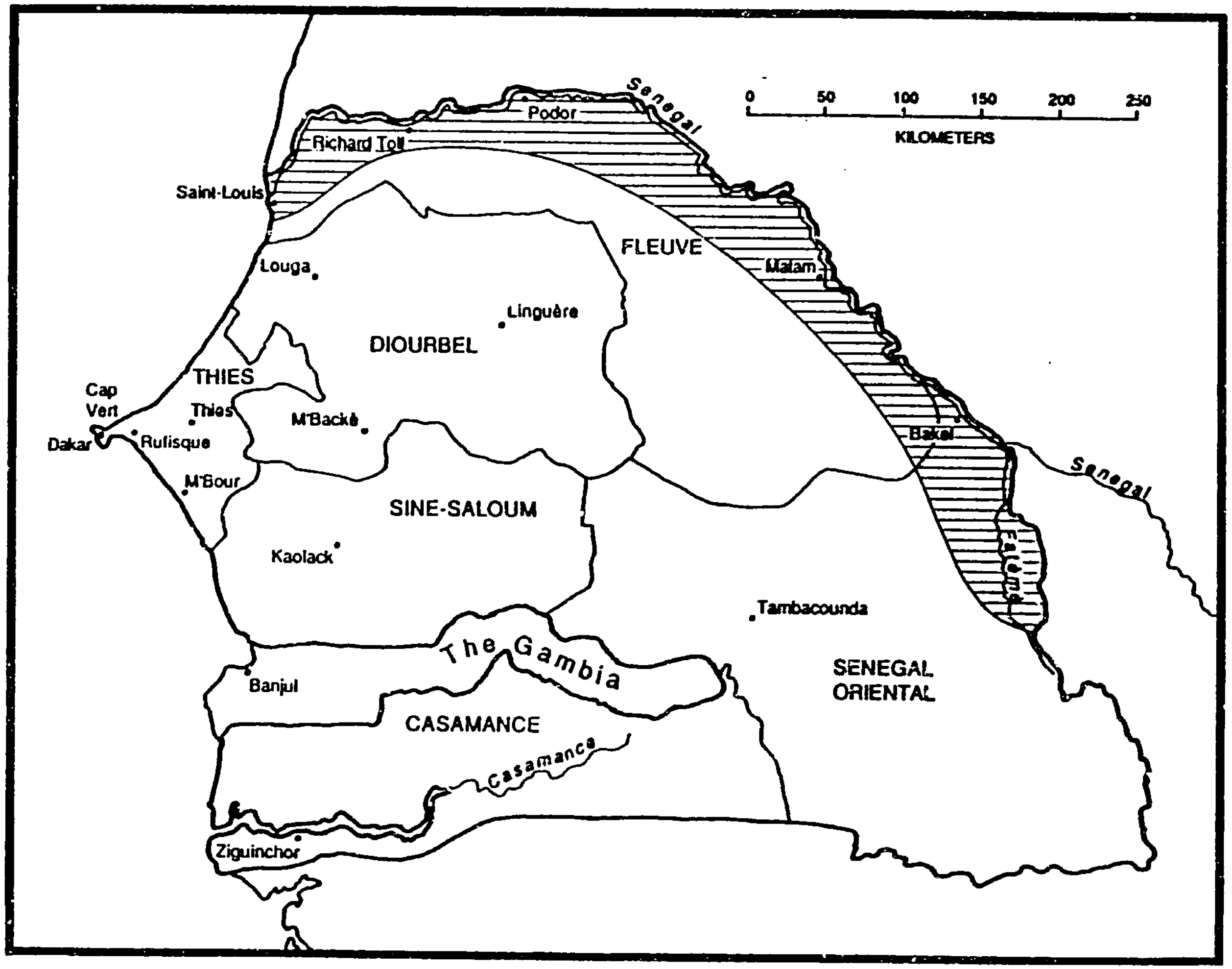


FIGURE 6

Irrigation Along the Senegal River, Senegal.

further expand its VIS program, 117 small perimeters had been established in the Matam area, with a further 92 around Podor and Aere-Lao, and 27 in Bakel region (see below).[1] The term "Matam Irrigation Scheme" thus refers in actuality to over a hundred small perimeters strung out along the Senegal River and totaling 2,140 ha. SAED's "third generation projects consisted of its more controversial attempt to extend the Matam model past Bakel into the narrower and more difficult upper river zone along Senegal's far eastern borders with Mauritania and Mali. Before looking at the Bakel experience, however, let us note the present distribution of SAED's efforts in the Senegal Valley and also reasons for the return to larger-scale projects now that the ambitious OMVS river basin program is coming on line.

The allocation of support effort to Senegal's irrigation looks very different depending upon whether total hectares covered or the number of perimeters assisted are used as the measure (Table 14).

TABLE 14

DEVELOPMENT OF IRRIGATION ALONG THE SENEGAL RIVER

Country	Total ha:	Ecological Zone:	Total ha:	Scheme Size (ha):	Total ha:	Percent of total schemes:
Mali	270	Delta	19,000	Large (500+)	21,000	4
Mauritania	5,305	Middle Valley	8,000	Medium(50-500)	2,000	6
Senegal	23,230	Upper Basin	1,000+	Small (50-)	5,000+	90

Source: Miller (1985), p. 41.

By grouping its small perimeters into larger "schemes," SAED portrays its effort as being directed towards 14 schemes, half large ones and half clusters of the VIS type. According to Dumont's unpublished FAO figures, SAED in 1983 had 18,478 ha within its assisted perimeters, with winter paddy the predominant crop (12,220 ha) giving nearly 50,000 metric tons

[1] These details about Matam are derived from an unpublished case study compiled for FAO's Land and Water Division in June 1985, by D. Dumont.

with an average yield of 4.5 tons per ha. These figures are impressive when contrasted against the low number of perimeters and yields within Africa's other official irrigation schemes. In Senegal, the costs of production have been lower on the small perimeters (estimated by SAED at 54.1 CFA per kg in contrast to 87.8 at Dagana), being roughly equivalent when charges are included to the import parity price. OMVS commissioned studies cited by Miller (1985:58) have found that throughout the Senegal basin, peasants on the small-scale schemes cultivate and harvest a greater proportion of the land actually developed than do the large schemes, and their productivity in average yields attained is higher.

These are significant observations, given the official intention that small-scale irrigation along the Senegal River should be phased out to make way for larger perimeters favored by OMVS planners seeking to justify the expensive OMVS dams along the Senegal River, the Diama salt-intrusion dam in the delta, and the Manantali dam upstream on Mali's Bafing River (Mournier, 1986). The OMVS[1], of course, requires large projects to justify the overheads involved in operating an inter-state organization linking Senegal, Mali and Mauritania. Formed in 1972 after the breakup of an earlier regional authority (OERS), the OMVS was given responsibility to develop the entire river valley--a process it claimed would halt desertification, end malnutrition, improve navigation, and raise the general standard of living throughout the area. Building and justifying the two dams have become the central preoccupations of the OMVS c'ganization.

The OMVS proposals seemed daring and technologically imaginative (though risky) when unveiled shortly after the Sahelian drought of the early 1970s had made bold proposals fashionable. The Diama dam (now completed) was sited 27 km upstream from Senegal's old colonial capital, St. Louis, at the mouth of the river. It is intended to block the incursion of salt water upstream into the middle valley during the river's low flow season each year, and is part of a larger complex including a future deep water port, a shipping canal giving access to the interior, and dikes to contain the freshwater reservoir behind the dam (Drijver and Marchand, 1985). It was estimated Diama dam would make possible irrigation of between 75,000 to 98,000 ha, drawing water from the freshwater lakes behind the diking system (Mournier, 1986:111). The complicating factor is the much larger Manantali dam, still under construction in Mali. A fully regularized flow on the Senegal River which is consistent with maximum hydropower generation would result in a loss of 67,000 ha currently irrigated or enjoying flood recession cultivation as traditionally practiced. This is balanced by 225,000 ha which the planners estimated could be gained for irrigation at full development of the basin's potential (Drijver and Marchand, 1985). In the interim, up to the year 2028, the sluice gates on the dam will be opened each year to give a reduced "artificial flood" so that presently developed small-scale perimeters can still be used. In the initial planning, it was decided that from 1987 onwards no further small-scale perimeters would be developed. Instead, the emphasis would be placed upon 1,000 ha fully mechanised units operated by development companies (Mournier, 1986:114).

The prominence of large-scale irrigation in the OMVS plans is no accident. It is essential to balance the otherwise largely negative impacts which can be anticipated from the project. It is worth noting the main points which critics have raised (Mournier 1986, Drijver and Marchand 1985):

- The navigational benefits are doubtful, since Senegal is already linked to eastern Mali by an underutilized railroad.

- The Diama dam will have a significant but unknown effect on Senegal's economically strategic marine fisheries, both through cutting off the annual nutrient enrichment which makes the Senegal coast so productive, and by reducing tidal spawning grounds for some species.

- Known saline soil deposits in the delta region may cause increased salinization of irrigated perimeters because of the raised groundwater table.

- There will be a substantial reduction in freshwater fisheries because of the decreased flooding of swamplands.

- There will be a substantial loss in seasonal forage which is otherwise produced on valley bottom lands after the annual flood recedes each year.

- Resettlement on the proposed scale will cause rapid deforestation within the basin, accentuated in riverine areas by the loss of the annual flood.

- Conversion to continuous flow and multi-cycle cropping will create ideal conditions for the spread of diseases already present at low endimicity.

- A fairly large population (10-15,000) must be relocated out of the 477 km^2 Manantali reservoir.

- To obtain the advantages of increased irrigation will require utilizing more difficult sites requiring greatly increased capital investment, perhaps costing as much as the dam itself.

- The installation of hydropower at the dam (with an eventual potential of 800 GWh) is being delayed, so that several years of siltation into the reservoir will occur without power benefits being realized.

- The dam itself will localize sedimentation within the reservoir instead of its being of positive benefit to farming communities downstream along the seasonally flooded riverine lands.

- The economic viability of the whole project depends heavily upon the rapid industrialization and commercialization of economic activity throughout the valley, a process bound to include pollution and other unanticipated negative impacts.

The OMVS planners have contingency plans to ameliorate many of the dams' worst impacts, as, for example, their intention that 28,250 ha of irrigated forage production will be added by the year 2028 (Drijver and Marchand 1985). This capacity they indicate will be devoted to centralized feedlots which will serve the urban sector, yielding an output of 5,000 tons of meat annually (80 percent of Senegal's estimated deficiency). And so in each area--transport, electricity, mining, irrigation, fisheries, and livestock production--large-scale units employing modern, capital intensive technologies are expected to insure the full utilization of the increased electricity and improved water control provided by OMVS.

These dramatic but as yet incomplete developments leave SAED in an awkward position. It has been accorded the official responsibility for carrying out Senegal's portion of the ambitious OMVS irrigation program--a program calling for a return to the types of production which SAED found unprofitable in the past. It is also clear farmers' high production costs and risks leave scant margin for recovering two sets of overhead charges. Paradoxically, it has been SAED's budget which has been most squeezed. SAED which in 1978 had an annual operating deficit of 800 million CFA was by 1980 an agency employing 2,000 people and spread over five zonal bases (at Dagana, Nianga, Aere-Lao, Matam and Bakel). Budget cuts instituted shortly thereafter reduced staffing to around 1,100 employees (Miller, 1985:40). Recent figures indicate SAED has 1,033 staff: 98 specialists (including 75 horticulturalists; 6 each of socio-economists, agricultural engineers, and agronomists; and 1 animal scientist), 40 administrators, 150 technicians, 238 extension agents, and 507 "implementation agents." SAED has been reorganized to increase its internal decentralization to the sub-regional level. In 1983, it was given authority to deal directly with donors in raising the 35 billion CFA ($90 million) investment required to meet its 1982-88 plan. Major donors (the World Bank, CCCE, FAC and USAID) have in recent years cautioned SAED to postpone new projects, rehabilitate old ones, transfer some planning and research activities to other ministries, and abolish its farm level subsidies (extended through undercharging for field services).[1] The Senegal Government has meanwhile (1982-84) imposed "performance contracts" on all its agricultural parastatals, anticipating a gradual *dépérissement* (withering away) of their functions as local associations (*groupements de producteurs*) and national companies take over the agency's role (Bloch, 1986:35).

Senegal does support other parastatals involved in one way or another with irrigation, notably its Institute for Agricultural Research (ISRA) with (in 1983) 1,300 staff (174 researchers) and a sub-station on

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[1]Staffing figures from De Vres, 1984, vol. 2, p. 233. Other data from an unpublished case study of SAED by D. Dumont for FAO's Land and Water Division, June 1985.

irrigated agriculture at Richard Toll/Fanaye, as well as an implementation agency like SAED but serving the southern, Cassamance region, SOMIVAC ("Société de mise en valeur agricole de la Cassamance"). SOMIVAC has 611 staff, including 87 technical specialists. Two of its three main projects, organized with USAID and the Chinese Agricultural Mission, include irrigation components directed towards improving "swamp rice" cultivation (De Vres, 1984, vol. 2, pp. 217-232).

The Bakel Project[1]

The "Bakel Project" as it has come to be termed is different from the usual situation wherein an external donor assists a single major scheme from its inception. "Bakel" is the name of a small town on Senegal's eastern frontier with Mali and Mauritania, located just below the juncture of the Falémé and Sénégal Rivers and across from the Guidimaka region of Mauritania (with Selibabi as its capital). As a department (district) headquarters, it has the usual array of government offices, schools, a hospital, and traders' shops--but it is by Senegalese standards remote and seldom visited. The "Bakel Project" refers both to an initial, PVO assisted village level attempt to irrigate 25 hectares from the waters of the Gassambilakhe swamp near Bakel town (Adams, 1977 and 1981; Miller, 1985), and to the whole cluster of small-scale perimeters taken over and developed by SAED under USAID funding throughout the Bakel zone (Table 15). Bakel zone is SAED's smallest and most distant sub-regional center, but it still encompasses 23 riverine villages spread along a 150 km stretch of the Sénégal and Falémé Rivers and irrigating 656 ha in all (Miller, 1985).

The history of how SAED came to be involved with Bakel explains much of the controversy which this project has generated. In Bakel unlike in the Tukulor and Wolof areas to the west), the Soninke predominates. While the Soninke are also found in Mali and Mauritania, their ethnic base astride a small section of the river deep in the interior leaves them a distinct minority within Senegal.[2] When SAED officials come to visit or work in Bakel, they cannot speak with the peasants in their own language, but must use French instead. For decades the Soninke have sought their economic fortunes by long distance migration, becoming at first sailors and then migrant workers in France itself. Many have retained ties to village associations, to which they remit money while living in France or elsewhere. They have also numerous trading ties up the river into Mali and across it into Mauritania. Thus while Bakel appears to outsiders as a remote place, it contains individuals who are

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[1]The main sources on Bakel include Adams (1977, 1981, Bradley et al. (1977), Keller et al. (1982), Patterson (1984), and Miller (1985).

[2]According to estimates, the Soninke speakers constitute only 2 percent of Senegal's population, in contrast to the Wolof and Lebou in the west (61 percent) and the Tukulors in the middle valley (11 percent, De Vres (1984, vol. II).

TABLE 15

SAED IRRIGATED PERIMETERS BY SUBREGION AND PERIMETER SIZE

(Area in hectares)

		DAGANA			PODOR		MATAM	BAKEL	TOTAL
		Large (Delta)	Large (Dagana)	Small & Medium	Large (Nianga)	Small	Small	Small	
Total Irrigated Area July 1, 1983		6,403	4,463	647	1,220	3,001	2,571	656	18,961
Area Planted 1983-84 Rainy Season	Total	6,466[1]	3,459	372	973	1,995	1,702	562	15,579
	Rice	6,446	3,459	372	973	1,742	1,416	418	14,846
	Maize	0	0	0	0	253	235	87	575
	Sorghum	0	0	0	0	0	51	57	108
No. of Plotholders		4,606	3,841	853	n.a.	14,316	7,974	3,863	35,454[4]
Average Holdings Size	A[2]	1.40	0.90	0.44	n.a.	0.14	0.21	0.15	0.41[4]
	B[3]	1.39	1.16	0.76	n.a.	0.21	0.32	0.17	0.50[4]
Average Rice Yield	A[2]	4.9	4.5	6.1	4.3	5.1	6.3	6.0	5.0
	B[3]	4.9	3.5	3.5	3.4	3.4	4.1	5.3	4.1

NOTES: 1) On one perimeter (Boundoum Debi) the data reported show that 200 more ha. were planted than existed in July 1983. It is possible that this land came into use between July 1 and planting time (later that month).

2) Variant A is average holdings size using planted area as the numerator, and calculating rice yields on the area planted in rice.

3) Variant B is average holdings size using total irrigated area as the numerator. Rice yields are calculated as tons of rice produced divided by total irrigated area, except for Podor Small Perimeters, Matam and Bakel, where Variant Ayields were multiplied by the ratio of total planted land to total irrigated land.

4) Excludes Podor Large Perimeters.

Source: Bloch et al. 1986, p. 40, derived from official SAED statistics.

relatively affluent and who have a sophisticated grasp of the modern world.

The idea for irrigation at Bakel originated with a migrant worker, Diabè Sow, then working in France and like others concerned about establishing a viable economic base in his home village. It was his decision to purchase a small irrigation pump and to seek French PVO assistance (from the Centre International de Dèveloppement Rural), leading eventually to an OXFAM funded, CIDR staffed small project at Bakel (Miller, 1985:65; Adams 1981). Through Sow's initiative, peasants in Bakel organized a village-wide association of 80 members, who dug a well and fenced their own village plot. The joint efforts of Sow and his PVO counterpart succeeded in attracting the interest of OXFAM and War on Want, which became sponsors for an enlarged effort. The CIDR technician meanwhile contacted a range of outside officials, including the Director of SAED and ultimately USAID. Discussion of a proposed $60,000 grant from USAID brought further official visits and in January of 1975 a formal application by OXFAM on Bakel's behalf, based on: 1) SAED taking overall supervision of the project; 2) peasant associations to enter contractual agreements with SAED; 3) the CIDR technicians (two to become three) becoming SAED agents, and iv) acceptance of $60,000 USAID funding (Miller 1985:66).

Bloch aptly describes what then occurred:

> When USAID was approached to provide pumps, it decided not only to do so, but also to expand the project to include better water control, bigger areas and more villages. Until this, SAED had ignored Bakel, because it was too small and too far away. . . . The USAID project, then, enabled SAED to intervene, and it did so with an arrogance that nearly caused the collapse of the village perimeters. It imposed crop rotations, technologies, input supply and marketing arrangements that were not only new to the farmers but misguided as well. . . . Rice was the required crop, even if it was not an important part of the local diet . . . and had previously been grown only sporadically, in <u>bas-fonds</u>, by women. It was to be grown everywhere, even on sandy soils which would not hold water properly. It was to be sold to SAED at unattractively low prices for processing and resale in cities outside the region. (Block, 1986:34-35)

USAID, on its part, was already working in the upper valley with livestock and health projects; the small-scale irrigation project for Bakel offered a chance to match World Bank and French activities downriver. By July of 1975 USAID received a SAED request for preproject funding of $124,000 to keep technicians in the field--an amount which grew eventually to $294,000 preproject expenditure on pumps, tools, studies, and support staff (Miller, 1985:72). Indeed, by the time an enlarged project was instituted in 1977, the total external financial support (including OXFAM and War on Want) had reached $569,000.

Meanwhile the Soninke villagers and their leader, angered by the takeover of their project and the many disadvantageous restrictions in the standard SAED contract, formed their own Soninke Farmers' Federation. It insisted SAED should not force villages to incur debts; the choice of crops and marketing channels was to be left to villagers' discretion; villages would retain the right to deal with other support agencies; and collective cultivation of a common, irrigated plot would be permitted. Miller points out that SAED has had to change its Bakel director several times as first one and then another tactic was adopted to counteract the federation's opposition (Miller, 1985:69). While the Senegal government did not approve the Federation's registration, the Federation initiated its own contracts with other PVOs and even obtained two tractors from the French Government (Bloch, 1986:35). This was SAED's first experience of active village participation coupled with a challenge to its expertise and thus authority. It had also never worked in such an isolated area where many villages could only be reached by river during the flood season, and where diesel and spare parts were unobtainable. Perhaps most significantly, SAED's technicians were from other parts of Senegal and lacked direct access to the peasants they were trying to assist.

Ultimately, it was USAID's financial backing which tipped the balance in SAED's favor. In 1977, USAID and the Senegal Government signed an $8 million, four-year project for assistance to Bakel's small-scale irrigation perimeters (with the US contribution being $5.9 million). The Bakel Project was USAID's largest involvement with irrigation in any of the OMVS states, and it led in turn to USAID assistance to the OMVS itself (Miller, 1985:73). The controversy surrounding the project did force changes in how SAED approached its Bakel perimeters. Crop choice is now left to the farmers, and SAED has lost its monopoly over input provision and marketing (Bloch, 1986:35). However, SAED still deals with village associations (termed groupements de producteurs) by means of a contract which their leaders must sign. The association remains jointly responsible for its members' debts, and in extreme instances SAED can threaten to shut a village perimeter down if debts are not repaid (Bloch, 1986:39). SAED divides the Bakel irrigation zone into three blocks, each with their own technical staff, but practically speaking much of the project administration originates in Bakel (Miller, 1985:123). In a few instances where individuals have built small perimeters, they hold individual contracts with SAED.

The small-scale perimeters operated by Bakel's villages employ a simple technology. Miller (1985:118-130) gives details on three of them, located at Bakel, Diawara, and Sébou. Bakel irrigation scheme, two kilometers downstream from the town, draws the water for its 20-25 ha of cleared fields from two permanently mounted diesel pumps. Diawara is located some 30 km downstream, and has 3 diesel pumps on floats moored to the river bank, which supply some 45 hectares. Sébou is 80 km upstream along the Falémé River, and has 2 diesel pumps supplying 22.5 hectares.

In the 1980-81 growing season, Bakel had 280 association members and six officers; Diawara had 343 with 16 officers, and Sébou 53 with four officers. Rice is grown as the primary rainy season crop, with current yields varying between 2.2 and 7.8 metric tons per ha at Bakel, 2.2 and 4.1 tons at Diawara, and 3.9 and 6.0 tons at Sébou. The lack of water in the dry season restricts cultivation at that time, when some farmers grow maize and mixed vegetables. At Bakel, the pumps tap residual runoff into the swamp. Since another perimeter uses the same source, close coordination is required. The lack of water prior to the onset of the rains makes it difficult to prepare rice nurseries on time, and in dry years the supply may be exhausted before the crop is mature.

While all villages are dealt with through GPs (groupements de producteurs), there are local variations in how the perimeter association decides to organize members' work. The number and size of internal work groups varies, and some villages maintain common fields as well as individual plots. If we take Bakel village's perimeter as our example, the perimeter has six collective work groups (with 10 or more members each) assigned to the six watering zones. These groups take turns in supplying required collective labor. Each zone receives water for 1-3 days from a single pump, with a six-day return period. Pumps operate between 9:30 a.m. and 6:00 p.m. each day. The work groups have their own ditch supervisors who are present when members' plots are being irrigated and who manage the distribution of water. Leaders are selected from within each group, and report directly to the Association's "Secretary General," the key person who coordinates all aspects of perimeter irrigation. Most associations have a plethora of unpaid officers, usually including many of each village's notables. There are six officers for Bakel's perimeter, which has been characterized by continuing tension between "functionaries" and actual farmers (Miller, 1985:124-130).

The fairly elaborate structure of offices and representatives found on many perimeters should not be interpreted to mean there is high peasant involvement in perimeter management. Office holders are in most cases those who initiated a project and are either self-appointed or nominated. Miller comments that:

> Many water users, especially women, understand very little about the irrigation operation procedure. They either watch and replicate what happens around them or wait until someone tells them what to do. Individual water users provide few inputs into the decision making process. Water user recommendations are seldom actively solicited by the officers or SAED. . . . (Miller, 1985:127)

Association leaders' greatest concern remains how to repay the seasonal debts which the groups accumulate with SAED. Most associations employ only one salaried person, the pump operator (paid usually 10,000 CFA per month). At Bakel, new association members are now charged a joining fee of 2,000 CFA (for men) or 1,500 CFA (for women) in addition to regular season charges. Other associations have solicited contributions from members absent working in Paris or Dakar. All three of Miller's case examples employ some outside source of revenue to lighten the burden of seasonal costs. Bakel draws upon revenue from a flour mill, donated by an ex-Minister; Diawara gets remittances from Parisien members of its Association; and Sébou has sold cattle to help repay its debts to SAED. As Miller points out (1985:131), the independent wealth found among the Soninke, their familiarity with trading and work remittances, and the tradition of external support for one's home village's projects have made it easier to repay SAED even when the irrigation enterprises themselves prove only marginally profitable. To these advantages we would add the tradition in some Islamic communities of assessing members for common obligations, requiring a form of simple record keeping not very different from that used in the irrigation groups.

As the price for external financing, SAED has had its Bakel perimeters subjected to numerous surveys and evaluations. A full external review by a five-person technical team (Keller et al., 1982) indicates the balance sheet on the project's achievements at the close of its four-year funding (late 1981).[1] The team's report makes several observations about the Bakel experience in relation to its possible replication throughout the Senegal River Valley (Keller et al. 1982):

- Projects should use whatever functional decision-making units exist (thereby favoring small-scale units).

- The fixed prices used by SAED had been a disincentive to farmers' adoption of irrigation.

- The Senegal USAID mission was found to have lacked the capacity and in-house expertise required for supporting and monitoring complex, multi-cropping irrigation projects.

- Counterpart relationships had been problematic and on-the-job training "almost completely lost."

- SAED's staff were judged to lack "hands-on field experience" in many instances.

- High rice yields of 7 metric tons/ha had been achieved, and with appropriate inputs other crops like maize and sorghum could show a similar response.

- Insect and disease problems had been minor, but the presence of "red rice" could still cause difficulties in the future.

- Farmers were experiencing problems in growing rice on sandy soils, indicating insufficient attention to soils when establishing perimeters.

- Poor pump maintenance and repairs were causing untimely breakdowns and a short equipment life "sufficient to destroy the economic viability of the Bakel Project."

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[1] An evaluation which preceded and is completely independent from this review, which has utilized the Keller report in the same way as other published sources on Bakel.

- Many pumping plants and penstocks were poorly designed, causing unnecessary malfunctions and shutdowns.

- Efficient layout of watercourses and adequate land levelling had not been achieved. "Farmers left to their own devices with inadequate hand tools and no tradition of using animal power are hardly up to the task."

- Standardization on a fixed pump size should be replaced by greater flexibility to suit different sized perimeters.

- Farmers were found to be growing their crops efficiently, but required additional extension and research assistance which the system was not yet prepared to give because of its lack of accurate farm-level data.

- The stress on import substituting rice production and its associated price distortions should be replaced by greater attention to farm level incentives and to the potential for growing other food grains.

- High labor requirements were found to be the primary constraint to expanding the size of irrigated plots within perimeters.

- It was stressed that packages for crops other than rice should be developed.

- The farmer federations found locally "should be formally acknowledged and incorporated into project management with SAED and USAID."

- Strengthening of accounting within the cooperatives was seen as critical for their long run success.

- The team endorsed the project's emphasis upon an integrated, farming systems' and rural development approach.

Finally, on a tangential issue, the report was highly critical of the likely cost-effectiveness of a large solar pump installation which had been put up at Bakel.

Other Irrigation Perimeters

Dagana[1] - The first "large" scheme developed by SAED, Dagana was designed to cover 2,400 ha (but actually has never irrigated more than 1,700). It is sited on river terraces and seasonally flooded depressions along the Senegal River, about 130 km upstream from St. Louis (to which it is

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[1]Details derived from an unpublished case study by D. Dumont prepared for FAO's Land and Water Division, June 1985.

connected by a paved road) and a short ways upstream from the Richard Toll plantations. There is a single rainy season (July-September) but the annual amounts vary widely, from 120 to 750 mm over the 45 years recorded. Traditional cropping was based on the usual combinations of millet, sorghum, and vegetables grown with décrue techniques, supplemented by about 160 ha of "floating rice" grown in riverside depressions ("cuvettes"). Mean family size was over 6 people, using on average 2.3 ha of riverine land and 1.5 ha of rainfed cultivation.

In 1973, following a 1972 World Bank identification mission, a credit agreement (for $4.5 million) was signed which lumped under a single project IDA assistance to the Debi, Lampsar, and Dagana perimeters. (Debi and Lampsar perimeters both occur within the Senegal delta between Dagana and St. Louis.) Physical works at Dagana anticipated a 19 km perimeter dike to protect against flooding, a storage reservoir, and 2,700 ha of land divided into three sections, each with its low-lift irrigation pumping station. Bank appraisal documents forecast paddy yields of 3.2 t/ha, with the addition of tomatoes, potatoes, onions, and sorghum into the rotation. Appraisal documents anticipated more than a sevenfold rise in family earnings by the sixth year of operation--assuming, of course, double-cycle cropping. Of the estimated $7.4 million required for the three projects, Dagana (at $6.14 million) represented over 80 percent. The foreign exchange component was $2.9 million, or 40 percent of the total for the three perimeters. IDA funds were provided to cover 60 percent of the overall total, with Senegal obligated for the remaining 40 percent.

Construction tenders were awarded in 1973, but the project suffered from immediate delays and cost overruns. While original costs estimates had allowed for 10 percent physical contingencies and 10 percent for price contingencies, actual increases exceeded these allowances and were additionally complicated by exchange rate fluctuations. By 1974, SAED was already in trouble in making its payments, and in the same year the Senegal Government requested reallocation of the credit to Dagana scheme alone, excluding the Debi and Lampsar perimeters. There were frequent interruptions of work at the site occasioned by various administrative and financial problems; the irrigation design was found to be too sophisticated, requiring a close degree of control and monitoring over the entire system. Equipment ordered also did not suit the anticipated cropping pattern. Two sections were eventually completed between 1973-79, but the third (of 375 ha) was left unfinished because of cost overruns (though part of the canals and the pumps were already installed). Between 1979 and 1982, the cropping intensity declined from 65 percent to 53 percent, leading to a rehabilitation of the first two blocks in 1982 and a cropping intensity of 74 percent in 1983.

Total rice production has remained less than 50 percent of the level expected in the feasibility studies. By SAED's own figures, one kilogram of paddy at Dagana cost the scheme 88 CFA to produce, almost exactly what it would have cost if imported (90 CFA/kg); adding in the differential for farmers' profits, Dagana rice became 30 percent more expensive than first quality imported rice. In fact, the problems SAED experienced with its highly mechanized, larger-scale perimeters (Dagana, Nianga, and

Podor) were a major factor in changing the emphasis towards less mechanized, small-scale perimeters (e.g, Matam, Bakel, etc.).

Nianga - The Department of Podor lies at the northernmost part of the Senegal River, at the start of what is termed the "middle valley." This is one of the driest parts of Senegal, with between only 300 and 400 mm rainfall on average per year. While the district as a whole has perhaps 150,000 people, the town ("commune") and its neighboring villages number about 14,000. It was originally a trading town, the headquarters for the pre-French Tukulor state of Fouta Toro established on the Senegal side of the river as protection against the Moors. With the decline in the gum trade and the opening of better transport connections to the interior, Podor went into a long period of decline. The traditional irrigation from low lying "walo" lands and the surrounding economy were especially hard hit during the 1968-73 Sahelian drought, when many men left the area to seek their fortunes near Dakar.

The Nianga perimeter was begun in 1966, but is supervised from Podor, 10 kms away. In 1972 agreement was signed with FED for construction of a 20 km dike to provide flood-control over some 9,000 ha, while permitting SAED to reclaim 2,000 ha for rice cultivation under "controlled flooding." In actuality, "flood control" meant cutting off farmers' prized "walo" lands from water during the low-water regimes of 1972-73. As one USAID consultant observed:

> The Nianga experience became notorious throughout the Middle Valley for its "destruction" of Walo lands and aroused considerable anguish and opposition to SAED large-scale perimeter projects among large segments of the population who relied heavily on their Walo lands.

It first had been intended to involve only four of the surrounding villages, but because of the furor over the loss of walo lands some 18 villages were eventually represented within the scheme.

The low water levels in 1972-73 required a replanning of the perimeter, with the aim being changed to achieve full water control over 750 ha under double-cycle cropped rice. EDF financed the flood protection embankment, pumping station, field levelling, and technical assistance (for three years after completion). Construction took place between 1973-75. From 1977 onwards, 630 ha have been under irrigation with the full 9,000 ha "protected" by dikes. As of 1984, there were 599 participating families holding on average just over one hectare each. These are organized into 36 mutual producers' associations, each responsible for one or two irrigation blocks. Average paddy yields were 4.5 t/ha, giving farmers a return per working day 50 percent higher than the official wage rate of 1,000 CFA. For the perimeter as a whole, cropping intensity was 74 percent in the main season and 35 percent in the off-season (Steekelenburg and Zijlstra 1985).

The Wageningen team which visited Nianga noted, however, that Nianga is not a financial success. There continues to be a large subsidy (of between 50-70 percent) on direct production costs (services and inputs).

The charges ("redevance") paid by farmers to SAED cover only about 40 percent of its costs, yielding an annual recurrent cost deficit by SAED of about 580 ECU/ha. Investment costs per hectare in 1983 constant prices are estimated at 17,600 ECU, yielding an EIRR of - 5.1 percent (Steekelenburg and Zijlstra 1985). While SAED continues to exercise overall managerial control over Nianga, it has tried in recent years to delegate more tasks to the producers' associations. Other sources dealing with Nianga include Weiler (1979) and Weiler and Tyner (1981).

Mali

National Background - The Republic of Mali is a land of contrasts that range from the Guinea zone of the south (more than 1,100 mm annual rainfall) to the Sahara in the north (less than 200 mm). Between these two extremes is the Sudanic Zone (600 to 1,100 mm) and the Sahel Zone (200 to 600 mm). Because most of the country lies in the arid and semiarid zones where rainfall is highly variable, the government has made a commitment to the expansion of irrigation as a means of increasing food production.

Mali is dominated by two major river systems, the Senegal and Niger, with their respective tributaries. Both rivers rise in the Fouta Djalon highlands of nearby Guinea. The Senegal River flows from the southeast approximately 100 km across western Mali into Senegal. Irrigation potential on the Senegal River in Mali is generally limited because of the rugged terrain through which it flows. The Niger River flows for 1,700 km in an arc from the southwest cutting through each of the ecozones to Tombouctou before flowing southeast into the Niger Republic. In many respects the Niger River and its tributaries are the lifeline of Mali, with population concentrated along the river valleys and the Niger Inland Delta.

Estimates of potential irrigation vary considerably from 340,000 ha by FAO (Table 2) to over 1 million ha (CILLS-Club du Sahel, 1979, Mali). Regardless of the total potential hectarage, there is no question that Mali has the greatest potential in West Africa and could conceivably become the "breadbasket" of the region. The regional distribution of potential irrigation and the developed irrigation perimeters are summarized in Table 16. According to this table, only 20 percent of the potential has been developed.

There are currently 69 irrigation perimeters encompassing 157,000 ha of irrigated land. This figure includes 56,000 ha of the Office du Niger (Table 17). Most of the irrigation development has been funded by external donors. France has provided funding for the Office du Niger and continues to support expansion and development. The World Bank and Dutch are providing assistance for rehabilitation and management for the Office du Niger. Chinese assistance has developed sugarcane perimeters at Dougabougou and Siribala. Operation Riz-Mopti and Operation Riz-Ségou have been funded by the World Bank, while USAID provided funding for Action Blé Diré and Action Riz-Sorgho-Gao. USAID will be involved in minor irrigation development in the Kayes region under a proposed

TABLE 16

ESTIMATED POTENTIAL IRRIGATION BY REGION

Region	ha Potential	ha Developed
Kayes Region	1,000	219
Southern Mali	70,000	4,435
Upper Niger Valley	100,000	1,650
Segou Region	200,000	38,650
Inactive Delta (ON)	250,000	56,000
Active Delta	100,000	35,410
Lacustrine Zone	100,000	17,720
Niger Bend	60,000	2,600
TOTAL	881,000	156,684

Source: Projet Inventaires de Ressources Terrestres, Mali. Bamako: USAID/TAMS. 1983.

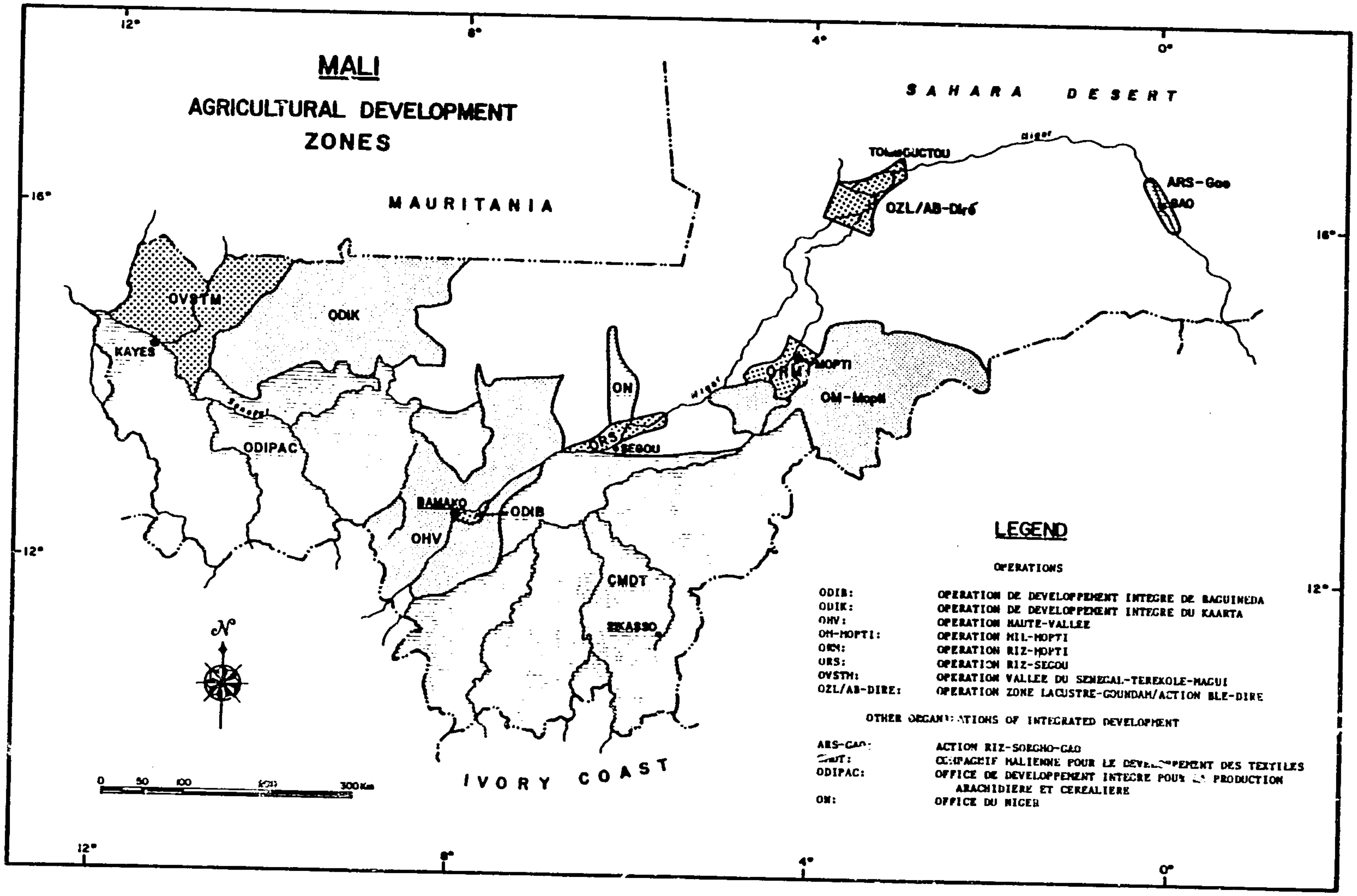
integrated rural development program.

There is no single government institution that has sole responsibility for the development and organization of irrigation. Agricultural development, under the aegis of the Ministry of Agriculture, is delegated to regional development organizations. The Office du Niger is a large-scale scheme which is responsible for development of irrigation in the Inactive Delta. It is an institution with financial and administrative autonomy.

In other areas of the country agricultural development is the responsibility of the operations such as the Compagnie Malienne de Developpement des Textiles (CMDT) in southern Mali or Opération Vallee du Senegal and la Térékol et du Lac Magui (OVSTOM) in the Kayes Region (Figure 7). Usually these operations will have a division that oversees irrigation development. Other Operations such as Opération Riz-Ségou and Opération Riz-Mopti have been created for the sole purpose of increasing the rice production through the development of irrigation. There are also the smaller Actions such as Action Blé-Diré and Action Riz-Sorgho Gao, where development is at a smaller scale than the Operations. All these development institutions have their own extension services, administration, study services and programming departments.

Planning and design of dams and irrigation networks is the responsibility of the division of Genie Rurale (Rural Engineer) of the Ministry of Agriculture. The actual construction of dams and irrigation

FIGURE 7



Agricultural Development Zones -- Mali.

TABLE 17
EXISTING IRRIGATED PERIMETERS

Name	Area ha	Name	Area ha
NIGER RIVER BASIN			
Southern Mali		Upper Niger Valley	
Gouéné	65	Nanguna	
Kado	200	Bankoumana	650
Korgouan	160	Krina	200
Loulouni	300	Samanko	500
Doumanaba	1,200	Baguineda	3,000
Kléla	100	Ségou	
Touroumadie	200	Tamani	8,900
Banbadougou	150	Farako	4,000
Langourala	280	Dioro	15,200
Samorossoni	140	Sosse-Sibila	3,450
Niéna	100	Ké-Macina	2,250
Farako	760	San Ouest	1,000
Sinkolo	70	Pénenesso	2,500
Dalabani	650	Kouniana	750
Faboula	60	Sourbasso	600
Inactive Delta		Zangasso	
Office du Niger	56,000	Lacustrine Zone	
Mopti		Kassoum-Soumpi	600
Saron-Tohbo	4,000	Koboro	2,500
Sofara	700	Zangaaso	
Torokoro	510	Dangha	2,500
Saré-Mala	3,120	Lac Oro	10,000
Soufouroulaya	4,500	Gara	1,200
Mopti-Sud	3,900	Dire	120
Mopti-Nord	5,800	Koryoumé	600
Ibétémi	300	Bourem Inaly	200
Karbaye	500	Bourem Sidi Awar	
Tiroguel	1,050	Niger Bend	
Ouro-Néma	4,130	Tacharan	2,000
Dramba-Kourou	400	Gargouna	600
Dia-Tenenkou	6,500		
SENEGAL RIVER BASIN			
Upstream from Kayes		Downstream from Kayes	
Sapou Kakoulou	15	Sobokou	40
Fanguéné	15	Moussala	25
Maloum	20	Gakoura	25
Dioumekon	12	Sebetokoura	7
Moussaguya	8	Kamankolé	10
		Danfagabougan	10
		Diala	12
		Samankidi	20

Source: Projet Inventaire des Ressources Terrestres, Mali. Bamako: USAID/TAMS, 1983.

networks is the responsibility of the Office des Travaux d'Equipment Rurale (OTER--Office for Rural Equipment Works). Agricultural experimentation, socioeconomic surveys and monitoring are the responsibility of the Institut d'Economie Rurale (IER--Institute for Rural Economy).

There are few, if any, communally managed irrigation systems in Mali. Most small-scale, traditional systems are individually managed. By contrast, the large-scale, controlled flood irrigation and total water control systems that depend upon modern technology have brought about government intervention and the creation of bureaucracies. Inevitably, this has led to a top-down approach and has generated difficulties in the smooth functioning of the irrigation perimeters. The Office du Niger is a classic example of management problems and animosity developing between government and individual farmers. Similar problems have been observed in the small-scale Actions.

Action Blé Diré[1]

Local Context. Action Blé-Diré (hereinafter ABD) in Mali's Sixth Region is an example of where a donor (USAID) decided to introduce small-scale diesel pump technology beyond the umbrella of support services. (In the Mali system, an "Action" refers to a pilot project launched with government support which, if successful, becomes enlarged into a full-scale "opération"). The site for the ABD Project is located on the northern banks of the Niger River, at the edge of the "lacustrine zone" where much of the Niger River's water overflows during high water periods into the southern margins of the Sahara Desert. This is the northern edge of Mali's "inland delta," a zone of flat, seasonally flooded soils which isolates the Diré region from the Mopti area 311 km southwards and from Bamako. There is no reliable road either to Mopti, or to Tombouctou (about 100 km northwards into the Sahara).

The Diré area has long been subject to trans-Saharan influences. Its leading families are the mixed descendants of Sonrai landholders and Morrocan troops, who invaded in 1591 seeking salt mines. Thus, Sonrai families have been growing wheat and making bread from before the time of the American Revolution. Koranic customs are followed, and women play a relatively minor role in agriculture (in contrast to African societies farther South). The central "arrondisement" of Diré had in 1975 a population of 21,360 (excluding the small town of Diré itself), of which almost 80 percent were Sonrai, the dominant ethnic group, and the rest being mostly Peuls (or Fulani) with a sprinkling of Bellah (Crystal, 1981:9). The larger area served by ABD under USAID assistance--including

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[1]This case study has been excerpted from, Moris, J.R. 1984, "Managing Irrigation in Isolated Environments: A Case Study of Action Blé Diré, Mali" African Regional Symposium on Small-Holder Irrigation, Blackie, M.J., ed., Harare, Zimbabwe, pp. 245-256.

the communities of Bourem, Diré and Dangha--has a population of roughly 77,000 (de Rafols, 1982).

The comparatively large population in the Diré area, despite its low rainfall (a 20-40 day growing season under arid conditions), is explained by the presence of alluvial soils and the annual Niger flood. The brief "rainy" season occurs in July-August, tapering off in September, and is throughout exceeded by potential evapotranspiration (Olsen, 1983). Rice and sorghum are cultivated on river front lands during the brief rainy season, the rice then becoming established in time to utilize the river's flood from October onwards. Wheat is planted in October-November, and harvested in March-April. There are also important secondary crops planted over the winter--vegetables (ocra, onions, tomatoes, cabbage), tobacco and spices--which are hand watered. Wheat requires 8,000 m^3/ha of water over its growing season of 110-120 days, or from 12-14 irrigations per season, whereas for sorghum about 4,200 m^3/ha is needed (Rafols, 1982). Rice would require a much greater amount if it were not being supplied by the Niger River's flooding. Existing wheat farming employed hand lifting of water into short, unlined channels which distribute it into small 2 m X 2 m hand-dug basins. Evaporation salts tend to accumulate on the ridges, while the clay in each basin holds the water for a day or two, allowing gradual infiltration. Olsen (1983) suggests the traditional basins ("cuvettes") are a good technical solution, but perhaps 30 percent of the water is being lost in the unlined distribution system. Under this system the most wheat a family could manage to cultivate was about 0.4 ha (roughly 1 acre). Pump delivery could result in a maximum of 4-5 ha per unit.

Project Components. ABD's initial activities were to set up its office and a medium-sized irrigation perimeter at Diré itself. Farmers rented land in this perimeter, but rice yields were low (600-700 kg/ha). As at Bakel, a large French solar installation was supposed to provide water but instead farmers have had to rely on diesel pumps. As an experiment in 1977, ten French Bernard pumps were supplied on credit to village notables in the surrounding area. ABD wanted another donor to expand its provision of pumpsets; USAID/Mali agreed to this.

It was recognized by USAID that assisting ABD would be difficult. The project area was remote, even by Mali's standards. Farms were almost entirely traditional and relied on hand-cultivation methods. On the positive side, farmers already knew how to grow wheat and were irrigating (albeit by hand). If better wheat varieties could be introduced, farmers would have a strong incentive to adopt them, since wheat is their staple food and the area is cut off from external markets. The area seemed free of wheat diseases. Some farmers were achieving yields equivalent to 5 tonnes/ha, better than elsewhere in Mali. It was planned that only excess wheat would be milled into flour for sale elsewhere in Mali. The pump technology was already in operation within remote areas of Senegal, and under proper use could permit 4 ha of wheat to be produced from each pump. With Mali Government support, it ought to be possible to import fuel and parts by river transport during the highwater period when wheat was being grown, and to export wheat by truck during the dry season following harvest. Finance for purchase of pumpsets, seasonal inputs and credit for participating farmers, and a system of logistics and servicing to keep the pumps operating was required.

The USAID Project Paper envisioned several components to circumvent the obvious technical and organizational problems which ABD was bound to encounter when introducing more pumpsets. The design was relatively complete: if each of the components had worked as planned, the project should have been a success. The kind of expensive siteworks which have been necessary on most other irrigation projects were avoided in this project.

First, USAID/Mali recommended small diesel pumps which two men could hand carry. The ABD Project has made a test case for ordering equipment from a Third World supplier, since Indian pumps following a Lister design were available at a quarter the cost of those from Europe. USAID took the precaution of advising ABD to order enough parts for the life of each pump, to be shipped with the pump itself.

Second, it was planned that four farmers would become the joint owners of each pump since one pump could handle up to 4.5 ha of wheat and one farmer on his own would have enough labor for only about one hectare (Rafols, 1982:23). This aspect was soon dropped under the opposition from farmers, leaving a single owner responsible for each pump. A village commission was also to be formed, composed of pump owners and elders, to scrutinize applicants for pump loans. Each loan would be amortized over a four-year period, requiring payment of 175,000 MF in annual installments. It would be co-signed by two other farmers who must promise to act as security for the loan. The village commissions were supposed to represent farmers in any disputes which might arise with ABD.

Third, the project design called for ABD to set up a special revolving account from which farmers' short-term crop financing would be provided (at 8 percent interest and based on non-subsidized, commercial prices). An interesting innovation was that these seasonal input loans (for fuel, seed and any other charges) would not be issued without the signing of a contract obligating the farmer to repay credit promptly within 30 days of harvest but also obligating ABD to supply fuel, oil, fertilizer, spare parts, and mechanics' services. A levy of 120 F/kg was initially foreseen to cover project operating costs.

Fourth, there were to be 8 contract mechanics to ensure maintenance and repairs during three years while local village youths would be under training to replace them. Six months in advance of the beginning of pump installation a repair shop would be constructed, and a spare parts system established. Farmers would pay for spare parts as required, but ABD would pay the mechanics' salaries during the initial period.

Fifth, ABD would upgrade its extension service in the project areas. It would also engage in an ambitious program of action research. Investigations would be launched covering a broad range of topics; socio-economic factors; appropriate technology for pumps, reforestation and even the undertaking of a functional literacy program. ABD would run agronomic trials to test fertilizer applications and to identify promising wheat varieties. Its experimental farm would include demonstrations on water control, wing beans, pigeon peas, sunflowers, etc.

All of this was to be organized under the standard USAID "host country" contractual arrangements whereby the ABD Director would be in charge of the Project assisted by a USAID supplied Project Analyst. While the Project Analyst was given numerous responsibilities within the scope of work as defined in the Project Paper, the position carried no authority within the ABD or, for that matter, the Malian administrative system generally. The ABD's Director was responsible for maintaining documentation on the expenditure of USAID supplied funds, in accordance with standard AID regulations.

Implementation Under ABD. When approved in 1978, the Project Paper envisioned rapid establishment of a logistic base in time for the initial delivery of pumps before the start of the wheat growing season in October 1979. There were delays caused by USAID's project preconditions. Funds were not finally released until August 1979. This one-year delay in financing meant that the pumps would be supplied for the 1979-80 season without farmers' receiving advance training in their maintenance, without the hastily recruited mechanics having tools and without the construction of the field workshop. In a heroic effort to avoid losing a year in the project's implementation plan, USAID/Mali decided to have the pumps it was ordering airlifted into the country. The enormous expense this entailed in turn made it mandatory that the project proceed with what was on hand for the 1979-80 season. When ABD submitted its budget in October of 1979, it proved unacceptable to USAID but to avoid further delay the project manager obligated 1/10 of the total and proceeded to make an advance of funds for operating expenses. Even so, the Project was able to install only 34 pumps in its first season and participating farmers were forced to plant late.

The Project's initial effort was concentrated in the Bourem sector, about 12 km from Diré. Later its activities were spread into villages into the Diré and Dangha sectors. At its maximum the Project was working with about 50 villages and 250 pumps. Since the average family size for pump owners was 11, there were approximately 2,500 direct beneficiaries. However, Action Blé Diré's involvement as the Project's executive agency became so problematic that in January of 1981 USAID froze further disbursement of fund. The Project did not resume field operations until September of 1982 when a second phase of "emergency" phase-out activities were launched by USAID.

From USAID's standpoint, the major problem in the first phase was the ABD's accountancy procedures. The ABD's head accountant worked "under the direct and constant scrutiny of the director" who kept the books himself (M ttern, 1981:13). There were no separate sections for budgeting or even salary payment. While the ABD's proposed budget for 1979-80 was not approved, as already noted, the Director did receive some funds to begin field operations. Meanwhile, there was no operating fund so when the Director was absent all disbursements ceased.

A severe and continuing cash flow problem was caused by ABD trying to make its key equipment purchases using incorrect procedures. When farmers did begin to repay their loans at the end of the first wheat season, ABD used the funds to pay its operating expenses rather than placing them in a special, blocked fund as the grant agreement had stipulated.

A second area of immediate conflict arose in regard to the mechanical services which ABD was supposed to supply to pump owners. Spare parts were never inventoried, nor stocked in a warehouse. Lack of a repair shop meant that pumps waiting for major repairs were exposed to dust, sand, rain and wind for long periods and tools were often misplaced or lost. The Indian pump manufacturer diversified and discontinued the Project's model of Cooper pumps. Of the initial field mechanics hired, all were from the South of Mali and therefore did not speak Sonrai; half were neither good mechanics nor serious about their work. There were never enough tool sets, leading to borrowing, confusion, missed assignments, poor work and loss of tools.

The third and perhaps most crucial failure from the farmers' viewpoint was ABD's inability to provide the inputs farmers had been promised. In each of the first three cropping seasons ABD was unable to prevent a break in fuel supply during the crop's critical period. By the 1980-81 season, most pump owners had found ways to obtain small quantities of poor quality and expensive fuel from merchants in Tombouctou or elsewhere (Mattern, 1981:4). Seed supplies proved equally problematic.

The ABD extension effort was a failure. Smith found that only the very first of the pump owners had received any advance training from ABD; the second received none (Smith, 1983:9). Contact staff had only a technical training of a highly theoretical nature far above their actual comprehension. Extension themes for each cropping season were based on the agricultural operations elsewhere in Mali, not on local farmers' needs.

In spite of a continuing problem of non-payment of salaries and allowances, ABD continued to employ additional staff until there were 94 employees for 158 farmers, not including government employees in Diré. As of early 1981, ABD was paying 36,434 MF in salaries and allowances yearly on a total levy of 5,688,888 MF and an estimated total production value of 161,600,000 MF (Mattern, 1981:6).

In the 1979-80 season, ABD found farmers refused to pay the 10 F/kg levy because ABD's late installation of pumps and insufficient supplies of diesel fuel resulted in late seeding and poor harvests. Those who repaid any of their credit insisted it be applied only towards the purchase of the pumps, not towards fuel costs or the levy. By 1979 many of the 10 Bernard pumps were not working and spare parts were unavailable. When ABD could not provide spares, the village leaders owning and pumps refused to repay their loans--a further disinclination for repayment by other, less well-to-do farmers. Ultimately it was decided loans should be recovered in either cash or kind. About 15 tons of wheat were received from the 44 participants in the 1979-80, season, but this required a heavy administrative input in making visits to farmers and in transporting the wheat back to ABD. Farmers had assumed the grain they paid ABD would be retained by the organization and reissued to them as seed grain. Instead, in 1980-81, when there was a shortfall of 30 tonnes of seed, ABD supplied seed only to those who had not already participated and then only enough for 1 ha each. As of May, 1981, when further USAID financing had already been frozen, the unpaid loans outstanding to ABD were about 56 million MF (Mattern, 1981:4-5).

Nevertheless, the Project did allow farmers to grow wheat. In 1981-82, the river water level approximated a 100 year "low" and many farmers without pumps were forced out of farming altogether. Thus it was decided that despite the evident financial irregularities within the ABD, the Project itself merited continuing support.

Project Management. In small-scale pump irrigation, the technical aspects of water management are sometimes less important than the overriding issue of supporting services and fuel availability. Diré lacks reliable road access or fuel storage capacity. To stay in operation the Project required unusually efficient and flexible administration.

It is easy to blame ABD's difficulties on its lack of managerial skills. Yet the combination of shared management, decentralized control, line item rigidity, scrupulous accounting, multiple objectives, advance planning and data intensive monitoring which was built into the Project design far exceeded what the Malian system could supply.

Implementation Under USAID. In the second phase of implementation (September 1982 onwards), USAID tried to provide the Projects's support by working directly with the village leaders and the political party, i.e., what was termed "activitiés paysannes." This strategem obviated the need to rely on ABD.

The main goal of the second phase was to get as many pumpsets as possible back into operation so that the Project could be officially handed over. While assisting farmers during the 1982-83 season, it was hoped the new Project team could get the long anticipated workshop built, recruit and train more mechanics, and re-establish a functioning spare parts system. The location of the engine manufacturer in India and the phasing out of the Project's model of pump tremendously complicated the whole process.

USAID's new field team soon discovered the same constraints which had afflicted ABD's field support efforts. There was insufficient repayment from the existing pumpowners to cover any fuel orders for the new season which was already beginning. Low rainfall in 1982 meant that farmers without pumps lost their sorghum crop. The 1982-83 wheat season was again a low water year on the river, and the consequent drying up of the side ponds ("mares") normally used by farmers to extend irrigation. Thus, pumps were pressed into double duty, supplying water from the river into the "mares" and then again from the "mares" to the fields (Smith, 1983:3). The first delivery of fuel for the wheat season did not occur until 21 December. This late start meant that crop maturation was delayed into the time of high temperature and (in early 1983) unusually high winds, requiring still more pumping. The supplier provided the wrong oil, causing breakdowns. When the river levels dropped unexpectedly early, the Project's final shipment of fuel became stranded on barges somewhere upstream in the inland delta.

The various trip reports and field memos submitted in connection with the campaign to resurrect farmers' pumps provide an insider's view of the real work problems which such programs can be expected to encounter in remote African environments. Both the pre-ordering on parts and the maintenance of the pumps was highly problematic in such a remote environment (Buchanan, 1983).

Further, the mechanics were severely limited in regard to what parts they could carry with them. Inevitably, there were unanticipated needs and if an item was not available the field team would be forced to take a "better" part off somebody's broken pump to fix another pump which would be repaired.

Project Impact. The Project Paper specified that ABD should be assisted by the services of an on-site social scientist (Crystal, 1981), whose report gives a preliminary picture of pump owners. Of those receiving pumps, 21 percent had non-farm occupations, either as religious leaders ("marabouts") or as school teachers. (There were some traders, but these were already farming.) The pump owners controlled more than twice as much land as non-pump owners: an average of 7.0 ha versus 2.8 ha; of this wheat accounted for 2.6 ha versus .5 ha for non-pump owners. It seemed likely that pump-owners were generally the descendents of village founders. Most wheat (75 percent) was planted in fields by the main channel of the Niger, with a further 22 percent in locations served by flood recession points ("Mares"). In the 1980-81 season the area planted to wheat was increased about 19 percent over 1979-80, chiefly it seems by an ABD initiative which gained permission for farmers to clear areas along the river otherwise protected as forest reserves. Pump owners in general had greater wealth than non-pump owners, but it was difficult to get reliable answers on grain yields since this information could be used to increase farmers' ABD access and general tax liabilities. Farmers were also afraid that they might be besieged by neighbors asking for handouts, and sometimes even men's wives did not know for certain how much grain he had locked in his store. In the anthropologist's view, reported figures were below actual yields by up to about 30 percent. A "reasonable estimate" of yields being achieved on average was 1,500kg/ha (Crystal, 1981:44-5).

Perhaps the most dramatic effect of the Project was in reducing the work-time required for growing wheat. While a pump owner would put in 157.7 person/days per ha, a calabash irrigator would need three times as much effort, 483.6 person/days per ha. A significant difference is that the non-pump operators who must manually lift water usually dug longer and deeper canals, "frequently as deep as two meters by a meter wide and as long as 300 to 500 meters"--a task which sometimes took up a month's effort (Crystal, 1981:53). For calabash farmers who did not gain access to pumps, the Project had serious negative impacts: seed availability declined; labor costs more than tripled between 1978 and 1981; and various traditional forms of work and commodity exchange between households declined. Those "calabasiers" who tried to circumvent these consequences by association with pump owners earned little more than those who did not (Crystal, 1981:17-19). It was clear that whereas farmers used to rely upon unpriced reciprocal exchange to meet many household needs, they had now to learn how to calculate production costs in monetary terms. There were no significant differences between pump owners and non-pump operators in the kinds of tasks performed by women, e.g., seeding, threshing and winnowing. Of "natural" problems, water shortages and birds were the two major difficulties. (Women and children were reported to have spent from two weeks to a month guarding the fields before harvest, though only 3.7 percent of the male farmers interviewed thought it necessary to mention this as a woman's activity!) The most serious overall problem in the 1980-81 season was listed as "the incompetence of the Action-Blé staff" (Crystal, 1981:62-63).

The question of how much pump owners were actually benefitting surfaced as a priority issue when an economic analysis updated in early 1982 concluded the Project was not economically viable, since at an average of 1.5 tonnes/ha, wheat farmers would be making a loss of 198,313 MF per ha. Unless farmers could achieve more than 2.5 tonnes/ha or receive much higher wheat prices, their operation would still give negative returns (de Rafols, 1982:27). Why then were farmers at Diré and Bourem still eager to participate? A follow-up survey in the 1983 season found that earlier estimates missed two key facts: 1) in the poor rainfall years, such as both 1981 and 1982, farmers without access to pumps did not cultivate at all or else lost their crops; and 2) 86 percent of the pump owners were cultivating secondary crops such as onions, spices, or tobacco. While the areas planted to these other corps were low (63 ha versus 454 for wheat), the prices were not. At Niamey, a kg of spice can bring approximately 4,000 MF, versus 212 MF/kg for wheat at Diré. The investigator concluded:

> To summarize, the pump is not only less fatiguing than the calabash, it is the only means of cultivating enough land to feed the area's people. It is said here that the pump is responsible for repopulating the area. (Smith, 1983:17).

General Lessons of ABD. Many of this Project's difficulties stemmed directly from well intended actions taken in the initial year to make up for "lost time."

The decision to import Cooper pumps from India when there was no in-country parts supplier had disastrous consequences. The French Bernard pumps may not have been technically optimal, but at least their requirements are well-known in Mali and resupply of critical parts to Bamako from Paris can be arranged within a matter of days (if not overnight). If a project already suffers from logistic difficulties (as this one did), the imposition of an unsupportable technology all but guarantees failure.

To involve subsistence farmers in commercialized agricultural production means creating for them access to reliable input delivery systems, mechanics, spare parts suppliers, localized banking and transport, and adequate fuel supplies--all of which were lacking in Dirè. Existing planning guides do not prepare design teams to anticipate the complex requirements which must be met in moving a subsistence system into a fully commercial one in a single step.

Seasonal farm loans must be preceded by effective producer services. In virtually every season, the Project was late in getting fuel and seeds to farmers, thereby guaranteeing diminished output. Breakdown of mechanical services and fuel supply were frequent within the season. To advance seasonal crop plans under circumstances of such high levels of institutional risk was, in retrospect, a mistake. It is ironic that while the purpose of the pump irrigation Project was to reduce farmers' vulnerability to naturally caused production risks, by participating they became subject to greatly increased institutional risks.

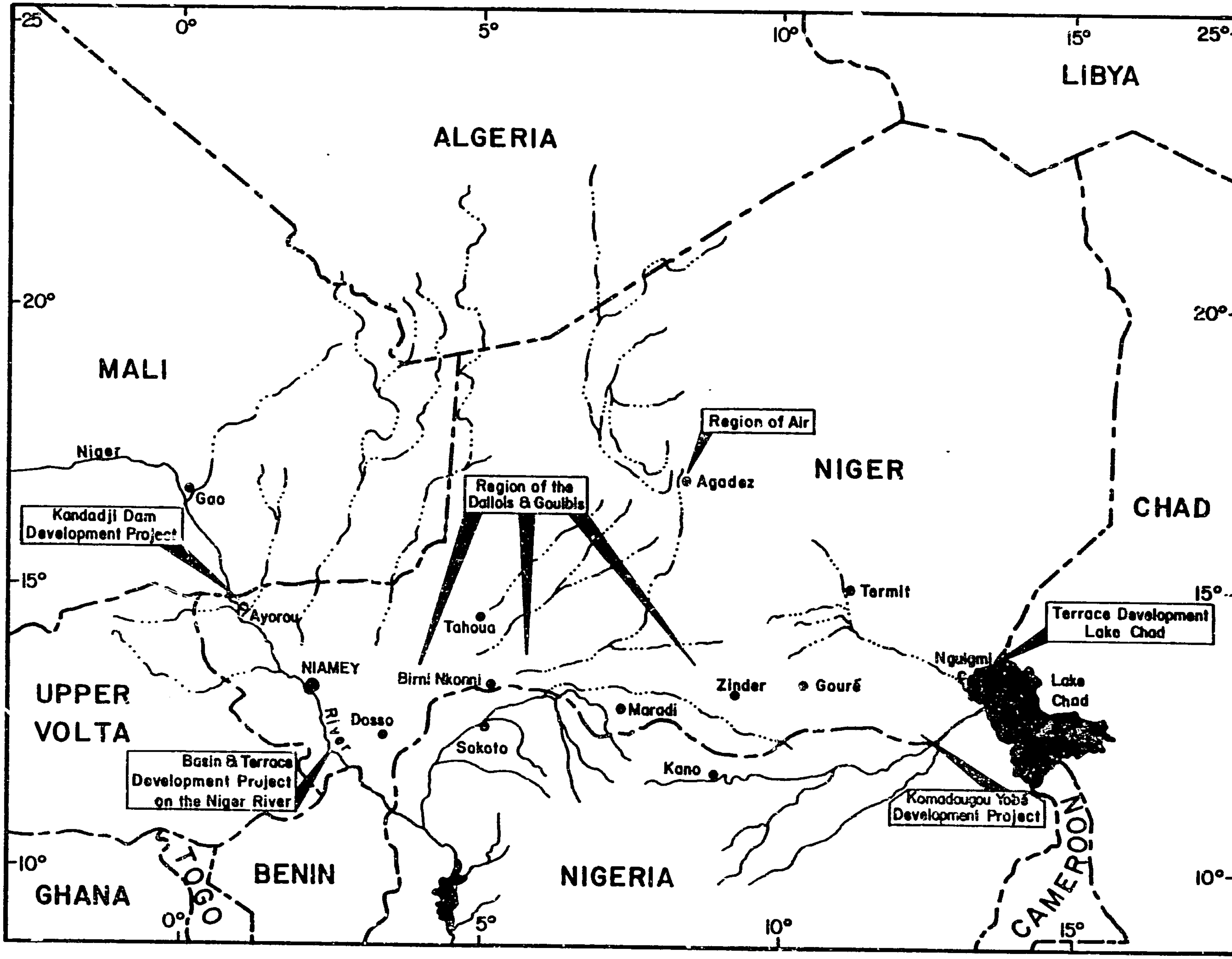
Finally, again and again staff were forced to make decisions which sidestepped the creation of an effective local capability which would have continued after the termination of Project funding. The high rate of pump breakdowns was a direct consequence of farmers' lack of understanding that proper maintenance is the crucial factor for long equipment life. Pumps which should have lasted ten years were being broken in two or three. Once this began happening, the field staff became preoccupied in responding to proximate demands which pre-empted their time and energies from creating long-run capacity. Thus, in development projects it is often true that unless measures to strengthen institutional capacity are instituted from the very beginning, project managers will become so involved resolving immediate problems that no change in effective institutional capacity will result.

Niger

National Background - The recent drought (1983-85) has further demonstrated the need for the expansion of irrigation in Niger. The government has given a high priority to irrigation development, but is constrained by a lack of financial resources and limited water resources.

The principal areas of irrigation potential are located along the Niger River, which flows across the southwest corner of Niger, around Lake Chad in the southeast corner, and to a lesser degree in the central region (Figure 8). The flow of the River peaks in January and February during the dry season at approximately 1,800 m^3/sec, dropping to below 150 m^3/sec in June-July at the beginning of the rainy season. Population is concentrated along the Niger River and the intermittent streams (goulbis) that form it tributaries. Villages have also been established along the fossil valleys, remnants of tributaries that once flowed into the Niger River during more humid prehistorical times. These fossil valleys (dallols) are characterized by a high water table and

FIGURE 8



Niger Irrigation Development.

occasionally may have a flow of water during an exceptionally rainy season. With water close to the surface, traditional irrigation techniques have been applied to cultivate these relatively fertile alluvial valleys.

Lake Chad, divided between Nigeria, Chad and Niger, is shallow, one to four meters, and has diminished significantly in recent years. The Komadougou Yobe is one of four tributaries of Lake Chad and forms a portion of Niger's southern boundary with Nigeria. Irrigation is carried on along the Komadougou and around Lake Chad were it is feasible.

Estimates of irrigation potential in Niger range from 100,000 ha to 220,000 ha. Most of the potential is located in the Niger River Valley. Along the Niger River Valley there is potential for 20,000 to 30,000 ha for double-cropping and 100,000 ha for single crop irrigation without the construction of a dam. Plans for the construction of the Kandaji Dam have been drawn, and estimates suggest that 140,000 ha could be irrigated. The high cost and the questionable viability of the Kandaji Dam Project has not attracted donor agencies to invest in the Project.

Extending from the Niger River to Zinder is a region characterized by dry stream channels (dallols), intermittent streams (goulbis) and hill catchment areas that provide water for irrigation. The potential in this region is estimated to be 40,000 to 50,000 ha. Estimates range from 15,000 to 25,000 ha in the Lake Chad region, with an additional 15,000 ha in the Komadougou River Valley. The variability in the estimates of potential irrigation is indicative of the lack of baseline data on soils and water resources.

Prior to 1978 irrigation development in Niger was primarily under the auspices of the National Union for Credit and Cooperatives (UNCC--Union Nationale de Crédit et Coopèratives) of the Ministry of Rural Development. UNCC planned, organized and promoted the development of irrigation through its technical, extension and marketing services. The Rural Engineer (Genie Rural) was responsible for planning, designing and construction of both large-scale and small-scale perimeters. In 1978 the National Office for Hydro-Agricultural Development (ONAHA--Office National des Amènagements Hydro-Agricoles) was created and the irrigation operations of UNCC were transferred to ONAHA. The responsibility of ONAHA is to manage irrigation perimeters and provide training and extension services to farmers on state supported perimeters.

The main office of ONAHA is located at Niamey, with regional offices in Tillaberry and Tahoua. In addition to the governmental institutions that are responsible for various facets of irrigation, there are a number of private volunteer organizations that have been active in promoting small-scale irrigation in different parts of the country. These include Africare, Church World Service, Lutheran World Relief, French Volunteers for Progress and Dutch volunteers. The projects of the various volunteer groups include digging and lining shallow wells, improving traditional irrigation systems, constructing small reservoirs and introducing motor pumps for irrigation.

Within recent years there has been an increase in the development of irrigated cropland. Between 1983 and 1985 irrigated land increased 9.4 percent from 9,117 ha in 1983 to 9,976 ha in 1985. The cuvettes, or basins adjacent to the Niger River, comprise over 51 percent of irrigated land (5,041 ha) and utilize dikes to control water during the flood season, but require pumping during the low water season. The Niger River terraces located above the floodplain require year-round pumping and represent only 4 percent (362 ha) of Niger's irrigated area. The remaining perimeters of the Goulbi and Dallols and Maggia Valley represent 4,573 ha, or 46 percent of the irrigated cropland. Irrigation development in Niger has been supported by a number of donor agencies. FAC and FED have been most dominant, although the Peoples Republic of China has provided assistance. World Bank is funding several rehabilitation projects, and with German assistance, constructed the recently developed Namarigoungou (Table 18).

The Tara Project[1]

Local Context - The village of Tara is located in the southern part of Dosso Department on the banks of the Niger River about 16 km from Gaya, the local administrative headquarters. It has 500 families, just over half of them involved in the rice irrigation component, with about 2,000 people living in the community and another 1,650 involved through linked activities spread over the larger area (fishing, etc.). In this part of southern Niger the annual rainfall is about 40 inches, sufficient for growing a range of crops: millet, sorghum, peanuts, rice and garden vegetables. The Project has four cooperatives: one for irrigated rice farming, another for poultry farmers, a third for 20 fishermen from the town, and a fourth for carpenters and blacksmiths. However, this description will focus only on the Project's irrigation and water management activities.

As it happens, the idea for irrigation at Tara originated with a Rhodesian farmer who came through during the great drought and decided to stay. He built the first dike at the river's edge and began growing peanuts. Subsequently his farm came under the control of the national peanut parastatal (SONARA) and then, in July 1975, the Niger government decided to turn the land back to the local people for small-scale farming. Africare was contacted and became the Project's executive agency responsible for implementing a $3.5 million investment program (drawing upon approximately $1 million USAID assistance.)[2] From its

[1]This case study has been excerpted from Moris, et al. 1984 "Prospects for Small-Scale Irrigation in the Sahel," Water Management Synthesis II Report 26, Utah State University, Logan, Utah, pp. 61-65.

[2]Africare is a private, non-profit organization established in 1971 when West Africa was experiencing one of the worst droughts in its history. Africare undertakes both short- and long-term projects and has work underway elsewhere in the Sahel.

TABLE 18

IRRIGATED PERIMETERS IN NIGER: EXISTING AND UNDER WAY 1985

Perimeter Site	Total Cultiv.	D.S.85	R.S.85	Number of Partici-pants	Date Placed in Service	Source of Financing	Cropping System	Observations
Niger River Cuvettes								
Namari Goungou	1,550	1,319	1,316	3,242	1982	IBRDKFW	Rice	Incl. 238 ha added in 1984
Toula	250	243	243	625	1975	FAC	Rice	
Sona	152	130	142	346	1975	FAC	Rice	IBRD rehab to add 15 ha to r.s. area
Lossa	164	142	157	403	1975	FAC	Rice	IBRD rehab to add 32 ha to r.s. area
Koutoukale	341	324	320	720	1982	FAC FED		Being rehabilitated by FED
Karma	-	125	125	300	1971	FED	Rice	Being rehabilitated by FED
Karegorou	143	-	135	437	1964	FED	Rice	Being rehab by FED to be completed in 1985
Kouretere	13	13	13	32	1970	(Belgium)	Rice	Belgians to rehab and add 10 ha to r.s. area
Kirkissoye	96	96	76	308	1964	FAC/FNI	Rice	IBRD rehab to add 15 ha to r.s. area
Sa'adia	105	105	104	396	1973	LYBIE/FNI	Rice	IBRD to rehab
Saga	380	374	350	1,081	1968	FORMOSA	Rice	IBRD to rehab
Libore		255	242	700	1973	P.R.CHINA	Rice	IBRD rehab to add 94 ha to r.s. area
N'Dounga I	250	255	231	770	1975	P.R.CHINA	Rice	IBRD rehab to add 82 ha to r.s. area
N'Dounga II	280	259	235	1,076	1978	P.R.CHINA	Rice	IBRD rehab to add 96 ha to r.s. area
Seberi	385	350	321	1,100	1980	P.R.CHINA	Rice	IBRD rehab to add 73 ha to r.s. area
Say	297	255	235	467	1978	Belgium	Rice	
Tara	76	27	40	300	1975	Africare	Rice	Abandoned
Firgoun	220	55	103	n/a	1983	Ent. Fund	Rice	IBRD rehab to add 50 ha to r.s. area
Daikaina	110	96	106	n/a	1964	n/a	Rice	IBRD rehab to add 7 ha to r.s. area

TABLE 18 (continued)

Perimeter Site	Total Cultiv.	D.S.85	R.S.85	Number of Partici-pants	Date Placed in Service	Source of Financing	Cropping System	Observations
Yalewani	118	110	112	-	1984	BOAD	Rice	To be completed in 1985
Tiaguirire Amont	111	n/a	n/a	n/a	1978	R.F.A.	Forage	Current status unknown
Tiaguirire Ava	n/a	171	168	-	1984 U.C.	FAC/PR.CHINA	Rice	Not completed by FAC, China will complete in 1985
Lamorde	n/a	n/a	n/a	n/a	1968	FNI	Rice	Current status unknown
Konroni Baria	n/a	-	n/a	-	U.C.	ABD	Rice	To be completed in 1987
Diaberi	n/a	-	n/a	-	Planned	FED	Rice	To be completed in 1986; being designed
Dombou	n/a	-	n/a	-	Planned	BOAD	For/Dairy	Unknown completion date
Namarde Gongou	n/a	232	232	-	U.C.	FED	Rice	Completed in 1984
Existing Perimeters	5,041	4,936	5,006					
<u>Niger River Terraces</u>								
Tilla Kaina	68	74	n/a	n/a	1962/83	FAC/FED	Vegetables	FED rehab in 1983
Sakoira (not existing)	42	-	-	-	1954	FAC/FNI	Polycult.	Abandoned
Gabagoura	30	n/a	n/a	n/a	1966	FAC	Vegetables Unknown	Sprinkles irrigation status
Lossa II	91	n/a	n/a	n/a	1975/76	FAC	Polycult.	INRAN substation
Sona II	71	n/a	n/a	n/a	1983	FAC	Polycult.	
Goudel	60	n/a	n/a	n/a	1975/76	FAC	Rice	Current status unknown
Sub-Total	362	74	n/a	n/a				
<u>Maggia Valley Perimeters</u>								
Ibohamane	750	611	590	600	1967	FAC	Sorg/Cot.	IBRD to rehab
Guidan Magagi	129	63	123	270	1971	FAC	Sorg/Cot.	Barrage damaged in 1985
Kore-Taboye (not existing)	57	-	-	97	1966	FAC	Sorg/Cot.	Abandoned
Monlala	72	14	63	124	1967	FAC	Sorg/Cot.	IBRD rehab to add 3 ha to
Tounfafi	24	11	23	69	1968	FAC	Sorg/Cot.	IBRD to rehab
Garadounme	75	n/a	43	57	1968	FAC/FNI	Sorg/Cot.	IBRD rehab to add 4 ha to r.s. area
Kawara	52	10	52	100	1968	FAC	Sorg/Cot.	Abandoned
Sub-Total	1,159	709	894					

TABLE 18 (continued)

Perimeter Site	Total Cultiv.	D.S.85	R.S.85	Number of Partici-pants	Date Placed in Service	Source of Financing	Cropping System	Observations
<u>Other Perimeters</u>								
Konni I	1,330	505	2,384	1,175	1980	Kowait	Polycult.	
Konni II	1,100			n/a	U.C.	Kowait	Polycult.	To be completed in 1984
Galmi	242	n/a	184	1,300	U.C.	KFW	Polycult.	To be completed in 1984
Goulbi Maradi	530	97	483	691	U.C.	IBRD	Polycult.	To be completed in 1985 to be well system
Lada-Diffa	52	n/a	43	n/a	n/a	n/a	n/a	Cuvette on Komadougou
Centre de Developpement Agricole de Diffa	20	n/a	16	n/a	1978	FED/CEAO	Polycult.	Cuvette on Komadougou
Tam Diffa	140	n/a	105	n/a	1977	FNI/CEAO	Polycult.	Cuvette on Komadougou
Sub-Total	3,414	602	3,215					
Total	9,976	6,321	9,115					

Source: ONAHA 1984.

inception the Project embodied the "new directions" approach which USAID and other donors were promoting in the mid-1970s, including:

- Execution by Nigeriens and their local institutions, with donor assistance only in areas needed to reinforce local capability;

- Inclusion of all the necessary components, applied research, transport and health and education facilities, making this an "integrated rural development project"; and

- Villagers' participation not only in food production but also in the organization and management of the Project.

Phase I of the Project had no less than 12 subcomponents: the construction of dikes and an irrigation system; rice production and research; cooperatives; credit; fisheries development; adult literacy; poultry production; appropriate technology; community development; construction of a farm-to-market road; primary health care training; and agricultural extension. Recently the Project has also begun working with well diggers to undertake cement lining of shallow wells.

Despite its multiple components, the primary justification for the Tara Project was the need to teach farmers how to irrigate rice under a regularized water control regime. The irrigated area consists of a long sliver of flat land on the bank of the Niger River that was formerly under traditional recessional irrigation. It appears the original dike was built with the intention of obtaining gravity flow irrigation. Under a Genie Rurale design, a new dike of 4 kms length was added in 1977 with pump intakes at the upstream end leading into a distributory canal system to the rice paddies. The primaries are cement lined, but the secondaries are unlined. Six Lister pumps with a theoretic output of 420 m^3hr were installed. The first design anticipated an irrigated area of 200 ha, later reduced to 140 ha because of high spots within the perimeter. As of the 1983 rainy season farmers had 73 ha under irrigation, with plot sizes ranging from .25 to .50 ha.

The rice cooperative has 256 members and supplies them with credit for seed, implements, animal traction if needed, and some training. Seasonal debts are recovered from the harvest, with a high level (85 percent or above) or repayment in the first three seasons but a marked drop to 57 percent in the fourth. Credit is advanced to the cooperative from the usual Nigerien Government institutions, the CNCA (La Caisse Nationale de Credit Agricole) or the UNCC. The Project also advanced additional funds for various special purchases, such as a rice dehuller or animal traction equipment. The irrigator's cooperative is in turn linked to others from the eight communities participating in Tara under a general assembly, which elects a five member administrative committee (president, secretary, treasurer and two bookkeepers) responsible for overall coordination and supervision.

Water Management. The primary problems in the Tara Project arise from serious design mistakes made in the early stages of the Project. It was originally conceived that the Project would provide water for both a rainy and dry season rice crop; however, the expectations of the latter have never fully materialized. The pump intake at the head of the system was set at a level which was based on a nearby bridge. There was no consultation on behalf of the designers with the local residents or farmers who no doubt had spent most of their lives along the banks of the river. As a result, the pump intake level has been above the dry season flows for most of the years since. Several attempts have been made during the dry season to move one or two of the four Lister pumps out on the dry riverbed and place them in series with portable pipe in order to reach the receded water level. The difficulty encountered here was in getting a flow rate high enough for water to reach the tail end of the system. Seepage through the cracks of the concrete canals compounded this problem (i.e., in pumping to the tail end of the system the cumulative seepage rate was higher than the output rate of the pumps in series). Attempts have also been made to dig out a channel to the receded water level from the pump intake, but this has met with little permanent success since high flows fill the dug channel with sediment. Farmers then tried to link up plastic pipes in series to the pump intakes, but the pipes soon split. Thus, at Tara the simple neglect of "ground truthing" by the perimeter's designers resulted in a continuing water supply problem which has been difficult to resolve.

Other problems can also be traced to faults in the design stage. Before implementation of the Project began, no soil survey of the area had been made nor was it called for in any of the Project papers. This resulted in the dike being partially built over an old sandbar as well as several areas within the perimeter being uncultivable due to large pockets of sand. Several areas in the lower half of the perimeter do not receive water through the canal network due to channels being lower than the fields. However, since most of these plots are in the sandier areas, during the rainy season when the river rises, sufficient water percolates under the dike up through the sandier soils for rice cultivation. Initially a pumping station was constructed and outfitted with several pumps at the tail end of the system for the purpose of drainage. This station has been neither used nor needed since most of the paddy water drains out under the dike as the river level recedes toward the end of the rainy season, and water delivery via canals to the end of the system is a problem, anyway. The reason that farmers have been successful in cultivating these marginal areas probably lies in their knowledge of traditional recessional rice cultivation. Many farmers maintain traditionally irrigated rice paddies in the rainy season outside of the irrigation perimeter. These farmers are opportunists and do admirably well with what they have; such is exhibited by the deepwater rice planted in most of the drainage canals between fields. Finally, poor design resulted in one of the two primary canals being built at the immediate base of the dike. Subsequent erosion of the dike by rainfall and livestock traffic has caused portions of the canal to be completely filled with sediment.

Africare's oversight and administration of the Tara Project, particularly with respect to the cooperative, is considerably more flexible than a typical ONAHA system. The resultant more "independent" system has both positive and negative consequences.

Maintenance, as with many of the projects visited along the Niger River, is a key problem. At the time of the site visit, labor competition with dryland cropping was the primary reason cited for poor canal maintenance. This competition was also causing serious water distribution difficulties. The cooperative president was trying to get the farmers to plant in the perimeter at roughly the same time, so that some type of orderly water distribution could be made. Many farmers were, however, still in their upland fields trying to get their millet harvested. The delay in planting rice not only complicates water delivery timing, it may also mean that those who plant late will have trouble getting their rice harvested before an onset of the seasonal bird problem. When asked about the weeds in the canals, the local perimeter director said the cooperative had previously scheduled that very day for cleanup, but it had been postponed to the following day so that the farmers could spend time killing birds which had become a more serious and immediate problem in their millet fields. This suggests that organizational problems within the users' cooperatives are not the sole reason for maintenance difficulties.

Other maintenance problems were noted in connection with the dike itself. It is regularly used as a pathway for livestock, which results in erosion. Larger weeds and shrubs were being allowed to grow along the slopes and in places these were planted to millet or maize--both of which could easily result in root cavitation. This seemed to be merely an information problem. A more serious problem was the many animal burrows which could be seeen along the sides of the dike.

Tara Project was visited by IBRD engineers, who recommended a whole gamut of further surveys to identify soils types precisely and assist in releveling of the fields. We consider the main problem to be the question of the intake design and levels; otherwise, farmers have developed their own solutions to what might appear as technical difficulties (e.g., planting floating rice in the partially flooded area between the two dikes). Perhaps it would be more realistic to acknowledge that in a 40-inch rainfall area there will always be a competition between rainfed farming and the second cycle of irrigated rice production.

Nigeria

National Background - On a population basis, Nigeria is virtually a case unto itself in sub-Saharan Africa. Nigeria's estimated mid-1985 population was almost exactly 100,000,000 people (99.7 m), well over twice Ethiopia's, over three times Zaire's, and over four times that of the other populous countries, Tanzania, Sudan and Kenya. Furthermore, much of this population is concentrated in the drier, northern half of Nigeria, where cities like Kaduna, Kano, and Sokoto are experiencing rapid urban growth. The demand for crops which can be grown under irrigation has expanded dramatically during a time when Nigeria's oil revenues provided the capital to begin large-scale irrigation investment (which Nigeria missed in its colonial period). Because of its oil riches, Nigeria is classified by western donors as a middle-income nation, leaving the country's irrigation development to be assisted by multilateral funding rather than by concessarionary bilateral aid.

Nigeria contains six distinct agro-ecological zones, ranging from coastal swamps in the humid south to Sahelian conditions in the dry north. The crops grown in Nigeria and the technologies being applied for their further development are shared across the zone, with close parallels to Benin, Togo, Ghana, Burkina Faso, and Ivory Coast. Nigeria is said to be West Africa's largest producer of rice (400,000 t annually), most of it *Oryza glabberrima* grown in flood plains under either traditional or to a much more limited extent, modern irrigation (Atanda et al. 1978). Nigeria's dramatic attempt to become self-sufficient in wheat production through large irrigation investments in the north is a cautionary tale which has many lessons to teach (Andrae and Beckman 1985).

Unlike Sudan, Kenya, or Senegal, Nigeria came to independence in 1960 without even a beginning having been made in developing the country's potential for modern irrigation.[1] There were a few rice irrigation schemes established by the colonial government from 1952 onwards in Nigeria's middle belt near Bida (northwest of the juncture between the Niger and Benue Rivers), but these totalled less than 2,000 ha in extent (Carter et al. 1983). Nigeria's first substantial irrigation project was the Bacita Sugar Estate (5,500 ha), built near Ilorin on the flood plain of the Niger River. It employs a mixture of sprinkler and surface irrigation, and is now run by a private company, though when built (in 1964) it was a joint venture between the government and Booker McConnell (Adams, 1986:192).

However, the main interest in irrigation within Nigeria has been and continues to be in the north. Here, because of the marked seasonality of

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[1]See Table 19 overleaf. Useful reviews of the history of irrigation in Nigeria are contained in Andrae and Beckman (1985), Adams (1985), and Palmer-Jones (1981). The first two sources have been used in compiling this section.

TABLE 19

HISTORY OF NIGERIA'S IRRIGATION DEVELOPMENT

1949	First irrigation division set up in the Northern Department of Agriculture.
1952	Rice schemes started in the Middle Belt near Bida: Wuya-Edozhigi; Loguma; Toroko; Badeggi; Lapai (ca. 1900 ha total)
1956	Establishment of hydrometeorological network around Lake Chad
1958	Pilot irrigation schemes begun on Yobe and Ebeji Rivers (Borno)
1959	Hydrological section set up in the irrigation division of the Northern Region Ministry of Agriculture
1961	Wheat schemes started in North Western State (Wurno, Tungan Tudu)
1962	Nigeria joined Lake Chad Basin Commission
1964	Bacita Sugar Estate built
1968	Kainji Dam completed; USBR Report on Kano River Project
1971	Military government invites tenders for design of Bakolori Scheme
1972	Feasibility studies for Savannah Sugar Company done
1973	South Chad Irrigation Project feasibility studies completed Chad Basin Development Authority created Sokoto Rima Basin Development Authority created
1974	Tiga Dam completed on the Kano River
1975	Construction started on South Chad Irrigation Project, Phase I
1976	11 RBDAs created by Decree of Federal Military Governmentq
1978	Bakolori Dam completed
1979	South Chad Irrigation Project Phase II begun
1980	Police action to re-establish control over Bakolori Scheme
1981	Kafin Zaki Dam construction commenced (River Jama'are) Goronyo Dam (Sokoto State) under construction
1982	Kiri Dam completed (River Gongola--Savannah Sugar Co.) Dadin Kowa Dam construction commenced (River Gongola)

Source: Wright, et al. (1982), pp. 10-11 with some changes.

the major rivers and the presence of a large human population near alluvial plains, irrigation has seemed the technical answer permitting intensified agricultural development. The Sokoto and Rima rivers, for example, provide 70 percent of their total annual runoff in just the two months of August and September (Adams 1985:192). Two major river basins span the northern boundaries of Nigeria: the Sokoto Rima Basin emptying into the Niger River on the west, and the Chad Basin whose waters feed Lake Chad in the east. Actually, for political reasons the Nigerian government has further sub-divided the Chad basin by carving out the Hadejia-Jama'are Basin around Kano from its western end. Today, all three basins have their own major irrigation projects: the Bakolori project southeast of Sokoto in the Sokoto Rima Basin, the Kano River Project south of Kano in the Hadejia-Jama'are Basin, and the South Chad Project northeast of Maiduguri on the plains adjacent to Lake Chad. Our interest here will be to trace briefly how these ambitious projects came into being, before looking in greater detail at the troubled Bakolori Project.

Although the first tiny irrigation works built by the colonial regime on the Sokoto plain--a few bunds and drainage ditches to improve flood control, costing L277--were later destroyed by the local people "amid great rejoicing" (Adams 1985:191), a small pilot project was eventually established in 1925 at Kware near Sokoto. Its poor performance over the years has been attributed by Palmer-Jones (1981) to farmer's lack of involvement, their distrust of governmental intervention, and the lack of actual benefits received. Eventually, Nigeria's first irrigation division was established in the agricultural department of the Northern Region in 1949, following a visit by the British West African Rice Mission which recommended increased flood control as a precondition for further paddy growing. Gradually attention shifted from the wet-season growing of rice to possibilities for dry season cultivation of wheat. Four areas were demarcated for further work: Wurno in the Rima valley (near Sokoto); Hadejia, northeast of Kano; and the Yobe and Gambaru sites west and south of Lake Chad (Andrae and Beckman 1985:80-81). The small schemes eventually put into operation were all based on pumping from rivers or small reservoirs: none required major dams or large canals.

After independence, Nigeria's 1962-68 National Development Plan identified the country's lack of irrigation as a major constraint retarding its agricultural development--a conclusion reached earlier in a 1954 World Bank report (Andrae and Beckman 1985:81). The Nigerian Government then obtained UN Special Fund financing to commission FAO to undertake a $2.88 million (US) survey of the soil and water resources of the Sokoto Valley. The study took six years (1962-68), and resulted in a six-volume report which conceptualized the area's future development in terms of discrete irrigation schemes which were investigated mainly from the standpoint of their physical feasibility. The disappointing history of northern Nigeria's seven existing projects was interpreted to show that economic yields were possible from irrigation, provided farmers were "properly indoctrinated" and more suitable institutional forms could be devised (Adams 1985, Andrae and Beckman 1985, Palmer-Jones 1981). At about the same time, USAID financed a parallel survey of the Hadejia-

Jama'are Basin undertaken by the US Bureau of Reclamation, and initially intended to identify possible extensions of an ongoing small-scale irrigation program. It, too, adopted an engineering perspective, took five years to produce, and was essentially an engineering reconnaissance survey to identify attractive sites for future physical development.

Neither the FAO nor the USBR reports dealt realistically with project economics. They judged that upland agriculture held little promise, and throughout assumed that stabilized production on the riverine flood plains based on water stored in the upper drainages was highly desirable. The downstream, "fadama" flood plains (particularly in the Hadejia-Jama'are drainage) were already intensively cultivated. The justification for recommending expensive upstream water storage had to be derived from an assumption that dry season crops such as wheat would be added. (It also required putting an extremely low estimate upon existing production.) While the USBR study attempted rudimentary economic analysis--one and one-half pages based on a three-month consultancy--no details as to which crops should be grown were specified (Andrae and Beckman 1984:82). It did claim, however, that the Kano River Project would show a nine percent internal rate of return.

The stress upon irrigated wheat production, which was to become so prominent in Northern Nigerian policy, arose from a joint FAO-World Bank mission report based on a visit to the proposed Bakolori Scheme area in 1967. Earlier FAO documents are reported as having been cautious about wheat, a crop which is difficult to grow in the hot tropics (Byerlee and Longmire 1986). The FAO agronomists noted that all crops excepting wheat which had been proposed by the engineers for irrigation actually grow better in the rainy season. Wheat became the preferred crop for the northern schemes because it could only be grown in the dry season, and because of Nigerian government concern about rising wheat imports.

Andrae and Beckman are justifiably critical about the lack of economic realism in the initial FAO, USBR, CDC, and IBID documents, but it should also be noted that those doing the site surveys thought it would be many decades before actual development commenced. Irrigation was so expensive and so speculative that nobody expected immediate implementation. FAO recommended a gradually phased development of the Sokoto Rima basin, starting with a 12,000 ha perimeter near Talata Mafara on the Sokoto River--itself to be cautiously developed in two stages because of the lack of local experience (Adams 1985:193). But these recommendations were soon overtaken by events. The then North Eastern State decided in 1969 to proceed with the Kano River Project identified by the USBR report. In the Sokoto-Rima basin, an Ad-Hoc Committee was established to review the FAO proposals, and in 1971 the Federal Military Government invited tenders for design work at Talata Mafara (Adams 1985:194). This was followed by a contract to Italian consultants for comprehensive studies and facility design, with fieldwork in the 1972-73 dry season and a completed Impresit report in 1974.

More generally, the mid-1970s marked a turning point for irrigation throughout Nigeria. Nigeria's oil boom coincided with the Sahelian drought and military rule by northerners. A federal deficit of half a billion Naira in 1970 was turned into a two billion Naira surplus in 1974, and by 1977 oil revenues had reached six billion Naira. The three large projects identified in the earlier engineering studies were now pushed ahead: the Kano River Project (20,000 ha) located 60 km south of Kano and drawing water from the Tiga dam; the Bakolori (or Talata Mafara) Project on the Sokoto River, planned for 23,000 ha; and the South Chad Irrigation Project (22,000 ha) in the extreme north-east on the shores of Lake Chad, from which it was meant to draw its water by pumping (Andrae and Beckman 1985:88-90). The fact these projects "were highly capital- and foreign-exchange intensive was no disadvantage at this point. The state had more foreign exchange than it could spend" (Ibid., p. 89). As Andrae and Beckman further note:

> [L]arge-scale irrigation seemed to offer a way in which state capital could move in a big way into the agricultural sector. Projects oriented towards rainfed smallholder production would seem to face more immediate bottlenecks as, for example, the need to train extension staff capable of handling a massive increase in inputs, credits, and technical services.
>
> Large-scale irrigation allowed the state to use its "surplus" funds to buy international expertise and advanced technology to produce an infrastructure which could then be placed at the disposal of the agricultural communities.

To military governors from the north of Nigeria, this seemed an attractive proposition, buttressed by their realization that Nigeria's wheat imports had been steadily rising.

Institutional Support - As could be expected, Nigeria's lack of earlier involvement with irrigation meant its federal Ministry of Agriculture was poorly prepared to cope with the sudden emphasis upon irrigation development. The first two river basin development authorities (RBDAs), modelled on the TVA in the United States, were established in 1973 for the Chad and Sokoto-Rima basins. In 1975, a separate Ministry of Water Resources was carved out of the Federal Ministry of Agriculture. In mid-1976, a full complement of 11 RBDAs covering all parts of Nigeria was created by Federal decree. As the maps given in Adams (1985) show, the initial RBDAs differed widely from actual drainage boundaries and also overlapped the state boundaries upon which Nigeria's budgetary allocations are based. A further revision of the RBDA boundaries was made in a 1979 decree. It retained the 11 authorities (Table 21) and specified their functions in greater detail (Table 22). It is plain the authorities were intended as multipurpose development and planning bodies responsible for a very wide range of activities.

The situation of RBDA's has been complicated by the fact they were a federal creation superimposed upon rival states and implemented without much regard either for the State Ministries of Agriculture or for existing Water Boards, which employ most of Nigeria's civil engineers dealing with water development. This competition did not matter at the start when funds were in surplus. More recently, however, it threatens to leave the less well endowed RBDAs stranded, having an ambitious

TABLE 20

IRRIGATED AREAS OF NIGERIA IN 1980

Basin Development Authority	Total area proposed (ha)	Areas irrigated December 1980
Sokoto-Rima	108,800	5,200
Hadejia-Jama'are River	75,009	7,009
Chad	157,500	2,000
Upper Benue River	309,700	110
Lower Benue River	130,750	677
Cross River	724,900	n/a
Anambra-Imo River	5,000	n/a
Niger River	243,200	448
Orgun-Oshun River	242,300	128
Benin-Owena River	n/a	n/a
Niger Delta	2,500	24
Sub-total	1,999,659	15,596
Commercial projects	47,200	6,978
State Government projects	n/a	8,132
Total	2,046,859	30,706

Source: Adams (1985), p. 195. Derived from Nwa & Marins, 1982.

Table 21

NIGERIA'S RIVER BASIN DEVELOPMENT AUTHORITIES

1. The Sokoto-Rima Basin Development Authority
2. The Hadejia-Jama'are River Basin Development Authority
3. The Chad Basin Development Authority
4. The Upper Benue River Basin Development Authority
5. The Lower Benue River Basin Development Authority
6. The Cross River Basin Development Authority
7. The Anambra-Imo River Basin Development Authority
8. The Niger River Basin Development Authority
9. The Oregun-Pshun River Basin Development Authority
10. The Benin-Owena River Basin Development Authority
11. The Niger Delta Basin Development Authority

Source: Adams (1985), p. 178, citing River Basin Authority Decree, 1979.

TABLE 22

FUNCTIONS OF NIGERIA'S RIVER BASIN AUTHORITIES

1. To undertake comprehensive development of both surface and underground water resources for multi-purpose use.
2. To undertake schemes for the control of floods and erosion, and for water-shed management including afforestation.
3. To construct and maintain dams, dykes, polders, wells, boreholes, irrigation drainage systems and other works necessary for the achievements under this section.
4. To provide water from reservoirs and lakes under the control of the Authority for irrigation purposes to farmers and recognized associations as well as for urban water supply schemes for a fee to be determined by the Authority concerned, with the approval of the Commissioner.
5. The control of pollution in rivers, lakes, lagoons and creeks in the Authority's area in accordance with nationally laid down standards.
6. To resettle persons affected by the works and schemes specified in this section or under special resettlement schemes.
7. To develop fisheries and improve navigation on the rivers, lakes, reservoirs, lagoons and creeks in the Authority's area.
8. To undertake the mechanized clearing and cultivation of land for the production of crops and livestock and for forestry in areas both inside and outside irrigation projects for a fee to be determined by the Authority concerned with the approval of the Commissioner.
9. To undertake the large-scale multiplication of improved seeds, livestock and tree seedlings for distribution to farmers and for afforestation schemes.
10. To process crops, livestock products and fish produced by farmers in the Authority's area in partnership with State agencies and any other person.
11. To assist the State and Local Governments in the implementation of the following rural development work in the Authority's area:
    a) The construction of small dams, wells and boreholes for rural water supply schemes and of feeder roads for the evacuation of farm produce;
    b) The provision of power for rural electrification schemes from suitable irrigation dams and other types of power stations under the control of the Authority concerned;
    c) The establishment of agro-service centers;
    d) The establishment of grazing services; and
    e) The training of staff for the running and maintenance of rural development schemes and for general extension work at the village level.

mandate but neither the resources nor the performance to justify further support. The rivalry with Water Boards should have been anticipated, since a dry environment any urban development will require water from the same supplies which are of interest to irrigation. Nigeria is fortunate in having had a thorough review of its irrigation manpower situation (Wright, et al. 1982), but there are still many unresolved institutional and policy matters to be addressed.

Bakolori Irrigation Project - The Bakolori scheme gets its name from Bakolori village, one of the many flooded in the reservoir when the project dam was constructed across the nearby Sokoto River. The project site is located 130 km southeast of the State capital at Sokoto. The 1974 feasibility study proposed a largely gravity-fed irrigation scheme of about 30,000 ha, two and a half times larger than what the original 1969 FAO report had recommended (Adams, 1984). The Sokoto Valley has on average a wet season of four months (June to September), and annual rainfall between 700 and 900 mm. The objective was to control river floods and to stabilize agriculture in the basin. Bakolori scheme along with a linked project, the Talata Mafara Irrigation Scheme, constitute phase I of the Sokoto River Basin Development Project, the major activity of the Sokoto-Rima RBDA since its formation in 1973.

The physical basis of the scheme is a 414 m concrete dam on the Sokoto River (pictured in Adams, 1985:195). It is an impressive structure, designed in the style of US dams of the 1950s with a 50 m high spillway at its center and nearly 5 km of linked embankments. The reservoir extends 19 km upstream, covering 8,000 ha which once contained 13,000 people. A 15 km concrete supply canal (some sources say 10 km) carries water downstream to serve some 27,000 ha of riverine terrace land near the town of Talata Mafara. Water is further distributed by 45 km of lined primary canals, and several hundred km of unlined secondary and tertiary canals. Original plans for a mainly surface system had to be modified because of soil porosity and now nearly half the irrigated area is covered by sprinkler irrigation. The sprinkler system depends on movable pipes and buried hydrants, and was about 70 percent complete by 1981 (Adams, 1984). A pump station and buried pipeline carries additional water to the 2,000 ha Jankarawa Scheme on the reservoir's north shore, near New Naradun where many of the evacuees were resettled. Approximately 40,000-50,000 people live in the project area. The construction contract itself was worth 174 million Naira in 1974 prices (roughly $400 million in 1982 prices). Average investment costs in 1979 prices were about 13,500 Naira per hectare (assuming full use of the planned area), in contrast to original estimates of 3,700 Naira/ha, excluding the hydropower and infrastructure components (PRC Nigeria Ltd 1982:27).

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[1]This account is entirely derived from various papers by Adams (1983, 1984, 1985) a case study by Beckman (1986) and further details in Andrae and Beckman (1985). Other sources include FAO (1969), Impresit (1979), Etuk and Abalu (1982), and Igozurike and Diatchave (1982).

The description just given would be how a project like Bakolori would appear in most official documents, which rarely describe how land is acquired and a system put into operation. The value of the detailed case studies on Bakolori supplied by Beckman and Adams is that they allow one to follow the process of scheme establishment step by step. Perhaps the most fundamental error made when construction began in 1976 was the failure to resolve precisely what would happen to the large number of people dispossessed from the reservoir. The initial plan announced to farmers would have given them cash compensation, followed by access to employment perhaps as fishermen on the reservoir or in the sugar estate which the Sokoto-Rima RBDA planned to establish on Bakolori's best irrigated land. The Federal Government subsequently ruled out direct compensation, insisting alternate land should be found for evacuees instead. The SRBDA then cleared land around new, upland settlements, but these were placed on heavily eroded and shallow soils which local farmers had already abandoned. In 1978 the reservoir began filling. Most of the evacuees refused the land offered them, and by 1980 the new settlements had become ghost towns (Beckman, 1986:142). Those who did not leave the area stayed on the margins of the boom-town economy which grew up around Talata Mafara. For others, however, the coming of the scheme was an economic disaster akin to a major drought (Griffith, 1983).

After much agitation, local authorities finally prevailed upon the Federal Government to agree that farmers could receive compensation for economic trees destroyed in the reservoir. However, the survey by students from Kaduna Polytechnic had to be rushed because the reservoir was already filling. Many farmers alleged they were never paid, and an inquiry was undertaken to trace what actually happened to the compensation money. Its report was never released, and meanwhile the aggrieved evacuees became the militant core for an emerging peasant resistance to the whole project.

As for those whose land would be "improved" by the scheme, the planners envisioned only a temporary hiatus in household production to enable the completion of necessary physical works. The theory was that land could be taken over at the end of the wet season, developed during the ensuing dry season, and handed back in time for families to grow the usual rainfed crops during the next wet season (Adams, 1984). This neat "solution" ignored the complications of operating heavy equipment on smallholdings, and the Nigerian government's interest in having scheme farmers grow wheat, which competes with farmers' own food crops because of an overlap in seasons. Land expropriation began in October of 1976 with a request by the SRBDA to the Local Government Authority at Talata Mafara for permission to begin construction work on the first quarter of the irrigation area.

Troubles surfaced at once. Most hard hit were those unlucky farmers whose land lay where the scheme map indicated access roads and service facilities had to be built. They lost trees, crops, and even houses, and had to wait several years before eventually their part of the scheme was ready to be handed back. (Resentment on this score was so great the scheme's service centers were nicknamed in Hausa "thief centers.") Nor had it been anticipated that a modern scheme contains a fairly large proportion of such facilities. Officially, it was stated that arable land was reduced only five percent by such excisions; internal project records indicate a 20 percent shrinkage, and one survey engineer admitted to Beckman that farmers' original holdings were reduced 40 percent (Beckman, 1986:143). Survey methods and compensation procedures had to be worked out as the project unfolded. While fairly sophisticated techniques were eventually evolved, the fact that almost everyone lost land and some farmers got none at all further polarized local opinion against the scheme.

Other difficulties arose in connection with cropping prohibitions. The contractor had assembled a huge fleet of heavy equipment, and approached its task in the customary fashion by levelling everything in sight so that equipment units could proceed to construct canals and drains. This meant farmers' access to their fields was blocked over much of the area, at first for one season and then two and sometimes for three years in a row. Disputes over compensation for the destruction of standing crops became commonplace. At issue were farmers' claims to guinea corn, their food staple, which is late maturing. The contractor wanted access to fields as soon as the rains finished in September, when the soil was easy to work. At this time guinea corn was still maturing, causing destruction of crops farmers had already planted and weeded. A temporary halt was called in 1977 by SRBDA to equipment entering standing crops, and again in 1978/79. By 1979 the project was falling behind schedule and the SRBDA thought it obtained commitments from village leaders that no guinea corn would be planted in any areas scheduled for construction. However, for some families this was their third season without food or compensation, and farmers widely refused to comply with the agreement. Other farmers were refusing to plant lands which had been handed back to them, in fear that if they did so their claims for crops destroyed during the intervening years would be overlooked.

Beckman (1986) gives a detailed account of the unfolding crisis, based on personal visits and interviews. We can only summarize the complicated chain of events here. In October of 1979 things came to a head when farmers began to blockade access roads to keep the contractor's equipment out of standing crops. Land survey and construction teams were subject to constant harassment, and began to travel with police escorts. Organized resistance spread in late 1979, once the state government had called in Nigeria's much feared "mobile police" units. The Deputy State Governor met with farmers' representatives and promised that compensation money would soon be received. But farmers were no longer satisfied with verbal promises. The situation continued to deteriorate, until high government officials could only visit the project area under heavy police guard. In early 1980, the Federal Government dissolved the board of the Bakolori Authority and charged a caretaker committee with inquiring into the causes of the crisis.

Now the opposition moved into a new and more strategic phase. By the end of February, farmers had taken control of the dam and its central power station. This affected the city of Sokoto, whose water supply downstream depends upon releases from Bakolori dam. The New Nigerian reported to the nation in late February that 5,000 farmers had blocked all entrances to the dam. Visiting journalists were forced to swear by Allah "that they had nothing to do with the Sokoto State Government" (Beckman, 1986:145). By early March, the investigatory panel had recommended the government pay the cash compensation it had initially promised, and the arrival of 19 million Naira for this purpose brought about a lifting of the blockade at the dam. Officially, the crisis was over.

Instead, the momentum of opposition swung back against the government when it became clear that while those displaced by the dam had been dealt with, farmers in the project area found their grievances unmet. The hasty infusion of Naira heightened tensions compounded by the absence of reliable land records (Beckman, 1986:146). On the 17th of April 1980, the blockade of the project was renewed although now shifted to the Impresit and consultants' headquarters at Birnin Tudu because the mobile police had taken up strategic positions around the dam. On the 21st, the blockade was reimposed on the dam site itself, and according to press reports staff were taken hostage but later rescued by the mobile police. Finally, on the 26th of April, anti-riot police entered the scheme in force while all journalists were excluded. The official death toll for the numbers of farmers killed was eventually given as 23. According to Beckman:

> A leading opposition politician . . . accused the police of having killed hundreds of villagers. He was arrested, but his case was only brought to court two years later. The police claimed in court that most of the names listed as killed . . . had been invented.
>
> According to an opposition paper, hospital doctors had been warned . . . not to leak any casualty figures. The foreigners . . . were threatened with summary deportation. One newspaper . . . claimed 386 people were known to have died. Another detailed list contains 126 names. It has not been challenged by the authorities. (Beckman, 1986:140)

From a wider perspective, the Bakolori crisis of early 1980 should be seen as a loss of innocence for Africa's irrigation planners. It should be recognized that Africa's earlier large schemes were designed and built without incident mainly because the land was taken from pastoralists who lacked modern arms and political influence.

It is still early to judge whether Bakolori will ever become economically viable. Maurya and Sachan (1984:277) now give Bakolori's capital cost as 21,500 Naira per ha, assuming 23,200 ha irrigated. The real figure should be much higher, since the design greatly underestimated water consumption needs on the scheme, making it doubtful that the full capacity will ever be realized. As for 1981/82, the scheme management was able to get about 5,000 ha under irrigation--but at a recurrent cost of roughly 2,000 Naira per ha, excluding capital repayment and SRBDA overhead costs (Andrae and Beckman, 1985:123). The trial balance accounts for 1982 showed scheme expenditures of over nine million

Naira, as against revenues of 390,000 Naira (Table 23 below).

TABLE 23

Bakolori Scheme Recurrent Costs, 1982
(in Naira)

Salaries and wages	1,980,240
Staff allowances	1,314,302
Staff quarters (mostly maintenance)	737,985
Offices (construction, maintenance, and equipment)	161,638
Electrification of quarters and offices	751,879
Motor vehicles (purchases and maintenance)	596,349
Plant and machinery (purchase and maintenance)	2,954,668
Fuel and lubricants	273,686
Maintenance of canal	73,348
Other items (livestock, fisheries, and forestry)	175,007
TOTAL (excluding dam, power station and HQ overheads)	9,019,147

Source: Andrae and Beckman, 1985:123.

Interviews with scheme staff cited by Andrae and Beckman indicated that Bakolori has received federal grants in the order of 8 million Naira each year during the period before the project became operational. The external management consultants now acknowledge that not only will Bakolori farmers make no contribution towards the project's capital costs; just to recover current expenses, the scheme would run at a deficit of between 3-5 million Naira annually.

Without any capital repayment, the wheat produced at Bakolori and Nigeria's other northern schemes costs conservative calculations between 800 to 950 Naira per ton, before transport to sources of consumption in the South where (at 1982 prices and exchange rates) imported US wheat could be purchased for 133 Naira per ton. Andrae and Beckman conclude that the factory gate cost of domestic wheat at Nigeria's leading flour mill was in 1982 some six to eight times the cost of imported wheat (1985:126).

Some of the blame for this situation must be attached to design and managerial faults not of Nigerian origin. The problem of insufficient water at Bakolori arises because consultants applied standard FAO formulae to calculate likely water demand, whereas special circumstances have resulted in higher than average consumption. The "intermediate" soil suitability classification applied to 78 percent of Bakolori's irrigated area turns out to have been over optimistic, and field managers continue to experience high infiltration losses and severe soil erosion. Away from the best valley bottom lands, soils are reported by Andrae and Beckman as being shallow, light, and sandy. The Jankarawa extension prepared at great cost for irrigation northeast of the dam turned out to have thin topsoil and numerous rifts and gullies: "the area is more suitable for military exercises than for farming, according to a frustrated farm manager who had failed miserably to grow wheat in the place" (Andrae and Beckman, 1985:107). The water delivery system consisting eventually of 500 km of buried pipes, 800 km of lateral pipes, and 160 electrical pumps, was dimensioned for 24 hour operation but in practice farmers have refused night irrigation. Then it was found that the high winds during the day when wheat was sprinkled caused pronounced puddling, so the system can only be used to the full during the morning and late afternoon hours (Ibid.). The scheme has been chronically short of energy to operate all its pumps. By 1982 a 7 MW diesel station had to be added to supplement the 3 MW hydroelectric station at the dam, and yet the supply of pumped water is still not sufficient to irrigate the whole of the planned area (Andrae and Beckman, 1985:105).

Meanwhile, the competition for labor between farmers' guinea corn and government mandated wheat continues. The shortage of water has forced scheme managers to choose between scheme and farmers' needs:

> Farmers interviewed at Bakolori pleaded for irrigation water . . . on their traditional crops, especially at times of poor rains, but management has not been able to accommodate them. Apart from design problems, management foresaw major difficulties with irrigation and field staff if supplementary irrigation was ever to be attempted on a large scale. Staff at all levels saw the wet season as a period when they were able to relax, go on leave, and attend to personal matters. (Andrae and Beckman, 1985:109-110)

There is no point in further describing Bakolori's various field problems, many of which are shared with Nigeria's two other large northern projects (see details on Kano and South Chad in Andrae and Beckman 1985). The attempt to speed up implementation when money suddenly became available lies behind many mistakes in all three projects. It is also clear that just because Nigeria produces less than two percent of the wheat it consumes does not automatically make wheat suitable for irrigated production in hot, tropical environments. The Nigerian Government's preoccupation with mechanized wheat production was a further cause contributing to the extremely low performance on its expensive northern schemes.

Sudan

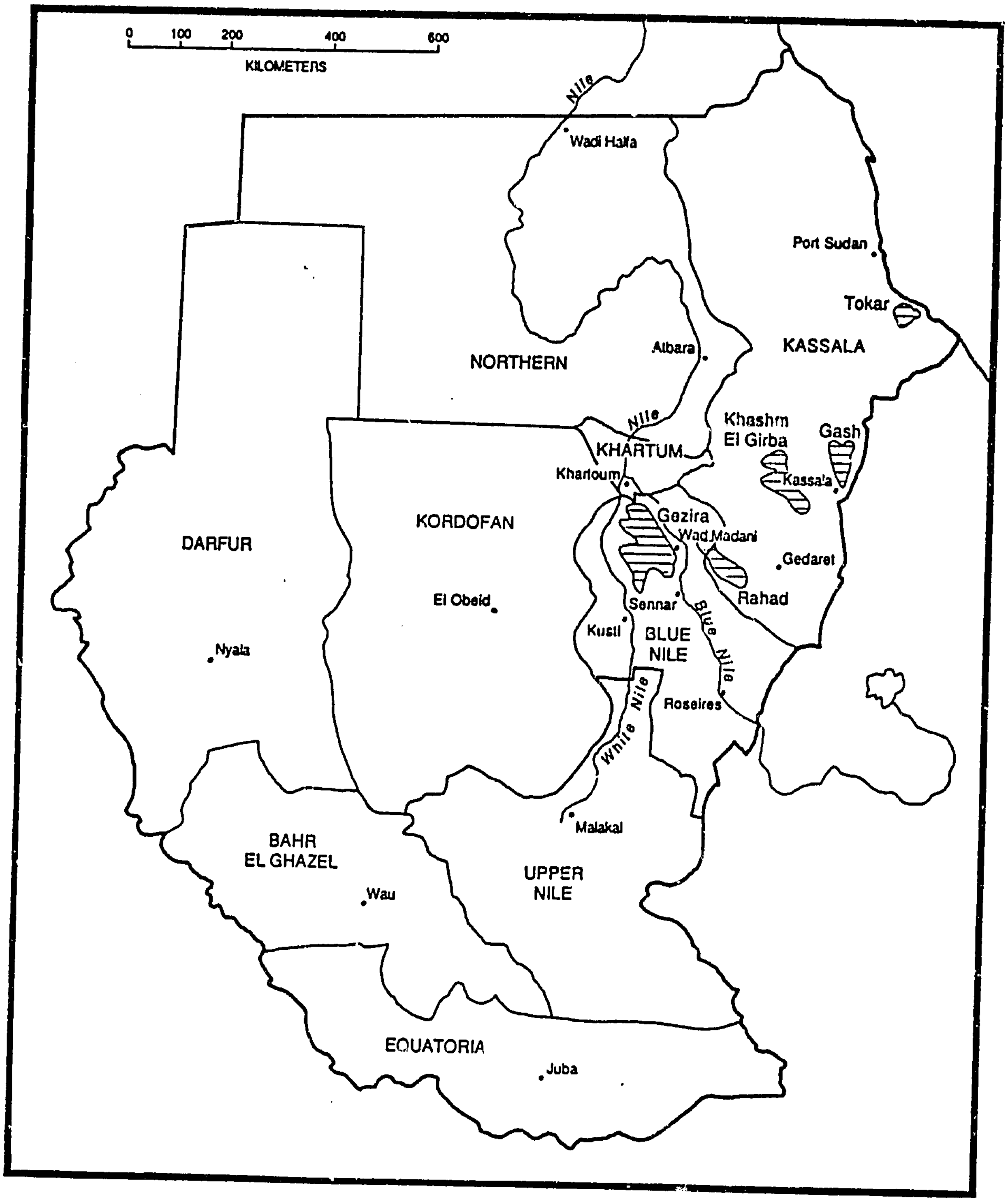
National Background - Sudan has the largest area (2.5 million km^2) of any African country, and its population of approximately 22 million (1985) puts it among the larger countries alongside Tanzania and Kenya after Zaire, Ethiopia and Nigeria. The different regions of Sudan have quite distinctive character, being in size larger than many individual African countries. To the north, the landscape away from the Nile is true desert. Development clusters along the river or around Lake Nasser, formed by the Aswan high dam (across the border in Egypt) which flooded the Old Nubian town of Wadi Halfa. To the northeast are the dry Red Sea Hills, with an Arabic speaking population of semi-nomadic Beja peoples and historic ties to the ancient kingdoms of Axum and Meroe in the times of the pharoahs. To the west are the hill-dwelling tribes of Darfur and Jebel Marra, amidst a pastoral zone extending into the West African Sahel. To the east are the plains of Butan and Kassala, originally occupied by nomadic groups such as the Arabic-speaking Shukriya, and more recently developed for larger irrigation schemes (the Rahad and New Halfa projects) north of the railway, and large-scale, mechanized rain-fed cultivation to the southeast. In the center of the country is Khartoum, the nation's capital and main industrial base which is actually composed of three adjacent cities (Khartoum, Omdurman and Khartoum north) which make up Greater Khartoum.

Sudan is possibly the only country in Africa with an irrigation sector large enough to show on small-scale national maps of land use (Abusin 1985). South of Khartoum a vast area of flat, clay soils between the White andd Blue Nile rivers has been developed under gravity fed irrigation. The Gezira Province is roughly 25,000 km^2 in size, and contains the one million feddan (420,000 ha) Gezira scheme and its linked Managil Extension (800,000 feddans or 336,000 ha).[1] The combined Gezira-Managil scheme is operated by the Sudan Gezira Board (SGB), and constitutes one of the largest irrigation complexes in the world. It will figure prominently, then, in any review of irrigation in Sudan--or, for that matter, in Africa.

The north-south flow of the Nile cuts across the different rainfall zones, with the lands north of the country's capital being too dry for any cultivation except by irrigation (almost all from the Nile itself). The early development of irrigation along the Blue Nile south of Khartoum from 1926 onwards led to rail connections northeastwards to Port Sudan and westwards into Kordofan and Darfur (see Figure 9). Over time, these created an east-west belt of human settlement linked through Gezira

[1] A feddan is only slightly larger than one acre (1 feddan = 1.039 acres). Different Sudanese sources vary in their estimates of the size of Sudan's schemes; these totals are based on El Agraa, et al. (1986).

FIGURE 9



Irrigation in Sudan.

to Khartoum and taking the form of an inverted crossbow with Khartoum at its uppermost and Kassala and el Obeid at the tips of the outer crescent. Most of modern Sudan's industry and development occurs here, fed by a zone of settled peasant agriculture along the line of rail northeastwards to the Red Sea and westards to Nyala in Darfur (Farah, 1985; Abusin, 1985).

From Nyala stretching southeastwards lies a less densely settled zone extending in a second crescent through Sudan's troubled southern provinces. These are cut off from the rest of the nation by a lack of north-south motor and rail links and by the enormous Sudd swamps at the confluence of the major tributaries feeding the White Nile. Except for Malakal, the entry for the north to the Upper Nile, all the other main southern towns lie in Bahr el Ghazal and Equatoria provinces reached mainly by air from Khartoum and constituting a distant hinterland far removed socially, politically, and economically from the country's emerging central zone (Mills 1985). The still incomplete Jonglei canal project was intended not only to augment the water available to the north (and to Egypt, its ultimate beneficiary but also to open up the south by a direct highway link parallelling the canal.

Sudan's irrigation is well described in the literature (see D'Silva 1986, Waterbury 1979, Clarke et al. 1985, el Agraa et al. 1986, and Fadl and Bailey 1984) and in numerous restricted World Bank documents. It includes five major types of projects: 1) traditional, small-scale irrigation; 2) pump schemes along the Nile; 3) larger, gravity fed schemes (like Gezira and Rahad); 4) spate irrigation on the Gash and Tokar deltas; and 5) parastatal or commercial estates (like the Kenana sugar project). In diversity, importance, and adequacy of documentation Sudan's projects would take priority in any overview of African irrigation. They acquire added significance, however, because Sudan is with Egypt a co-user of water which originates from sources in East Africa and Ethiopia not under agreement with either Sudan or Egypt. These geopolitical aspects are further complicated by the insurrection in Sudan's southern provinces and by the difficult ecological issues posed by the Jonglei canal project.

The distribution of rainfall outside of Sudan and the eventual flow of runoff through Sudan into Egypt are the two central facts with which any review of irrigation in Sudan must contend. With the minor exceptions of spate irrigation on the Gash and Tokar deltas and some small-scale oasis projects, virtually all of Sudan's large irrigated sector depends upon the river Nile's water (Waterbury, 1979). The Nile's average annual discharge measured at Aswan is 84 billion m^3, only slightly greater than that of the Rhine although the Nile is five times longer. The Nile's maximum measured flow was in 1878-79 at 150 m^3, and its minimum in 1913-14 at 42 bm^3. More than 80 percent of the Nile's annual flow used to occur between August and October in a seasonal flood. This water is received from three main sources: the Atbara River (entering from Ethiopia north of the Blue Nile); the Blue Nile (originating from Lake Tana in Ethiopia), and the White Nile (originating from Lake Victoria in East Africa and ultimately the Kagera River in Rwanda and Tanzania). The White Nile's water has been of particular interest to Egypt, whereas most of Sudan's irrigation development has depended upon water carried by the shorter and more sediment laden Blue Nile.

Sudan's second major dam, completed in 1937 on the White Nile at Jebel Auliya, was aimed largely at serving Egyptian interests. Because of the heavy silt load carried by the Blue Nile's flood, the 1900 Aswan dam built in Egypt could not be closed for water storage in each season until the flood's peak had passed. This left Egypt's farmers short of water in the first half of each year. The minimum discharge of the White Nile in May is five times that of the Blue Nile. Its silt load has been largely deposited upstream in the swamps of Uganda and southern Sudan. This explains why the Jebel Auliya was built in preference to a larger downstream structure and why it could be closed for storage earlier than the old Aswan dam.

It is important to recognize that the Aswan high dam built after Sudan's independence marked a radical break with the cautious approach adopted until then. The structure was not designed to pass the Nile's main flood downstream. Intead, it was sited to create an enormous storage reservoir (over 500 km in length), capable of holding two season's water and, by the same token, to accumulate the Blue Nile's large annual silt load as it comes off the Ethiopian highlands. The Aswan high dam segmented the Nile into two quite distinct parts, with its downstream flow becoming in effect a gigantic "irrigation ditch" subject to complete human control (Tvedt, 1986:10).

The benefits from this decision were clearly apparent in 1984-85, when low rainfall feeding the Nile would have meant disaster for Egypt's farmers had it not been for the huge size of the Aswan reservoir. Meanwhile, Egypt's ever-increasing need for irrigation water brought about the resurrection of a scheme first proposed in 1904 to increase the White Nile's flow by circumventing its "Sudd" swamps. Near Bor in southern Sudan the White Nile (known at that point as the Bahr el Jebel) enters a vast 180,000 km^2 area of seasonally flooded swamplands. Measurements of the river's flow above and below the Sudd undertaken as early as 1902-03 showed that about half the water was lost through evaporation. A 1904 report by Garstin proposed that a wide canal conveying 1,000 m^3 per second should be dug for some 340 km (nearly from Bor to Malakal). This measure alone, it was suggested, would double the White Nile's discharge during the low water season (Tvedt, 1986:35-37). After almost 80 years and many other proposals, the Sudan government did embark upon digging the Jonglei canal in a form not much different from Garstin's initial proposal.

Sudan's own irrigation is usually dated from the 1925 construction of Sennar dam to provide water for the Gezira Scheme. Actually, the first pumping station (serving 2,000 feddans) was built by the government in 1911 at Tayiba, on the Blue Nile below Wad Medani, and turned over to the Sudan Plantations Syndicate for management. Further stations were added several times between 1914 and 1924 under agreement with the Syndicate which retained the management concession. After Sennar dam in 1926 there were 300,000 feddans (126,000 ha) under irrigation, and staff had already accumulated 15 years of operational experience. These developments had not escaped Egypt's attention: in 1929 a Nile Waters Agreement was reached which allocated to Sudan enough water from the Blue Nile to irrigate one million feddans (420,000 ha). By the 1930's, then, Sudan's irrigation sector already exceeded in size that possessed by many other African countries today (El Agraa, et al. 1986:85-87). While the Gezira Scheme (described below) became Sudan's major irrigation commitment, the 300 km long reservoir for the Jebel Auliya dam made it feasible for pump irrigation to be developed on the White Nile. The Qoz en Nogara and other schemes were developed on lands below the dam, supposedly to compensate for the area flooded by the reservoir (Trilsbach, 1986).

By the time of Sudan's independence in 1957 it was clear that Sudan's 4 milliard m^3 water share out of the Nile's flow was grossly inadequate for the country's future needs (Taha, 1975). A second Nile Water's Agreement was reached in 1959, giving Sudan an increased share and allowing for the construction of the Roseires Dam which was to serve the Managil extension of the Gezira Scheme. From then onwards Sudan has implemented a success of major schemes on either the Blue Nile and its tributaries or the Atbara River: notably several huge sugar plantations as well as teh New Halfa (or Khashm el Girba) Scheme (built in 1962-69) and the Rahad Scheme (1973-78). While these are the best known projects because of the involvement of international financing, Sudan has added many others (see Table 24). What several share has been the bold decision to put dams with comparatively small reservoirs on rivers with seasonally high sediment loads. This necessarily means these projects will have a fairly short life: the reservoir behind the Khashm el Girba dam, which had 1.3 milliard m^3 water storage in 1964 had been reduced by sedimentation to an estimated 0.7 milliard m^3 in 1984 (Gallabi in Fadl and Bailey, 1984:71).

If we accept official Sudanese Government figures the country has today over four million feddans under irrigation, supplying the direct livelihood for more than 140,000 tenant families (Fadl and Bailey, 1984). The realities, while still impressive, are less clear-cut. Because of pronounced foreign exchange constraints, themselves in large part caused by low international prices for cotton and sugar (Sudan's largest irrigated crops), production has been severely depressed on several of the larger schemes as well as on pump-based projects unable to obtain diesel fuel. Gallabi, reporting on the New Halfa scheme in 1984, estimates the cropping intensities being achieved at 70 percent for cotton, and 40 percent each for wheat and groundnuts (in Fadl and Bailey, 1984:71). A few years earlier the figures for production would have been even lower. By 1980-81, Sudan's irrigation sector was nearly paralyzed: the Sudan Gezira Board had to organize direct transport of laborers from a distance to "rescue" blocks of cotton which had been abandoned unpicked (El Bagir et al., 1984:112). The Board's share of cotton profits in that year covered only 17 percent of its expenses, with the shortfall of 6.7 million Sudanese pounds being paid by the Sudanese government (El Agraa et al., 1986:98). Then the donors stepped in, with the World Bank extending credit for rehabilitation of several schemes and the Sudanese Government acceding to IMF demands for a major restructuring of the

TABLE 24

IRRIGATED AREAS OF THE SUDAN[a]

Source & Scheme (years when developed)	Annual Water required (mn.m³)[c]	Crop Intensity Percent	Cultivable Net area: (feddans)	Number of tenants	Rotation and Crops Grown:[b]
I. BLUE NILE					
Blue Nile Agr. Prod. Corp. (1950-65)	876 (P)	67	292,000	NA	C-S/G-F
Abu Na'ama (1973-75)	100 (P)	100	30,000	--	Kenaf
Es Suki (1971-72)	330 (P)	67	86,900	NA	C-S/G-F
Sennar Sugar (1972-73)	388 (P)	peren.	32,500	--	Sugar
Gezira-Main (1925-50)	4,000 (G)	75	1,135,400	48,350	C-W-S/G-F
Managil Ext.	3,600 (G)	100	946,300	53,900	C-W-S/G
Rahad Corp. (1973-78)	1,139 (P/G)	100	300,000	12,000	C-S/G V/Fr, dairy
Guneid Sugar (1950-54)	230 (P)	67	38,700	2,320	Sugar/G
Guneid Ext. (1964)	180 (P)	83	45,400	2,000	C-W-S/G
Seleit Livestock (pvt.)(1973-74)	NA (P)	100	20,000	--	Fodder
Private pumps (1935-present)	165 (P)	NA	63,500	NA	NA
II. WHITE NILE					
White Nile Agr. Prod. Corp. (1950-67)	830 (P)	75	359,600	NA	C-W-S/G-F

TABLE 24 (continued)

Source & Scheme (years when developed)	Annual Water required (mn.m^3)^a	Crop Intensity Percent	Cultivable Net area: (feddans)	Number of tenants	Rotation and Crops Grown:[b]
Hagar Asalaya Sugar (1974-77)	363 (P)	peren.	29,000	--	Sugar
Kenana Sugar (1976-80)	968 (P)	peren.	81,000	--	Sugar
Private pumps (1935-present)	70 (P)	NA	28,000	NA	NA
III. ATBARA					
New Halfa Agr. Prod. Corp. (1962-69)	970 (G)	100	330,000	22,000	C-W/S-G
Halfa Sugar (1962-69)	210 (G)	100	19,600	--	Sugar
IV. MAIN NILE					
Private pumps (ind. & coops)	730 (P)	100	208,000	NA	M/S/O-W/WL/Ct/D/Lucerne
Northern Agr. Prod. Corp. (1930-present)	430 (P)	100	103,000	NA	M/S/O-W/WL/Ct/D/Lucerne
Basins	40 (P)	var.	40,000	NA	M/S/O-W/WL/Ct/D/Lucerne
V. OUTSIDE THE NILE SYSTEM (estimates)					
Gash	--	NA	80,000	NA	S/or castor
Tokar	--	NA	30,000	NA	S

TABLE 24 (continued)

Source & Scheme (years when developed)	Annual Water required (mn. m^3)[a]	Crop Intensity Percent	Cultivable Net area: (feddans)	Number of tenants	Rotation and Crops Grown:[b]
Aweil Rice Scheme	--	NA	5,000	NA	rice
North Darfur small-holders	--	NA	3,000	NA	S/Fr/V & Ct
TOTALS:					
I. BLUE NILE	11,018		2,990,700	118,570	
II. WHITE NILE	2,231		497,600		
III. ATBARA	1,180		349,600	22,000	
IV. MAIN NILE	1,200		351,000		
V. OUTSIDE			118,000		
TOTAL SUDAN	15,629		4,210,000	140,570+	

[a]Source: Fadl, Osman and C. Bailey (1984) Water Distribution in Sudanese Irrigated Agriculture, pp, 4-6.

[b]Key: --Water source: P = pumped, G = gravity

--Crops: C = cotton, W = wheat, S = sorghum, G = groundnuts
F = fallow, V = vegs., Fr = fruits, M = maize
Wl = winter legumes, Ct = citrus, D = dates

economic system.

One hears that these rescue attempts have been effective, reinforced by a boost in farm incomes following price revisions and the adoption of individual farm accounts. Others report that donor imposed changes have enjoyed "less than complete success" (D'Silva, 1986). The grounds for pessimism derive from the larger context of Sudan's irrigation development. In retrospect, it is clear that for three decades the Sudanese government has relied upon its high cost sugar and cotton production as the mainstay of its irrigation economy, supported by a ponderous bureaucracy and by an attempted mechanization of much of the field production. The mechanized operations and the many pump-based schemes (roughly one-third of Sudan's total irrigation) depend entirely upon imported fuel and parts. Furthermore, the low sugar and cotton prices received in recent years are likely to persist into the future, jeopardizing Sudan's export earnings upon which the whole system depends. As Sudan's reservoirs built under loan financing fill with silt, the country will face yet another crisis to add to its recurrent problems of drought and rebellion in the south. Thus although Sudan has by far the largest irrigation sector in Sub-Saharan Africa, the prosperity of its irrigation systems and their tenants may yet prove illusory (Barnett, 1977, 1981).

An advantage but also a liability Sudan enjoys in trying to make its large irrigation sector more efficient is that the institutional infrastructure is well developed and generally understood. This provides a wide base of potential resources to draw upon in the short run, but makes the system resistant to radical changes. At the top, the national Nile Waters Commission determines the allocation of water quotas between provinces and regions within Sudan (Phillips in Bloch, et al., 1986:74). Next come the ministries and corporations. From its early dealings with the Syndicate, the Sudan Government has evolved an arrangement whereby the Ministry of Irrigation (MOI) builds and supervises the water supply systems, but hands operational control over the production aspects to public and parastatal corporations--the Sudan Gezira Board (SGB), the Northern Agricultural Production Corporation (NAPC), the Es Suki Agricultural Corporation, the White Nile Agricultural Production Corporation, the New Halfa Agricultural Production Corporation, and the Rahad Corporation (to name only the larger ones). There are in addition separate corporations to manage the various sugar plantations and other state farms, as well as certain individual schemes too large to fit within the normal framework for the pump-scheme sub-sector, e.g. the 30,000 feddan Zeidab scheme which would otherwise fall under the NAPC's supervision. The large number of such bodies has not caused confusion because most are territorially distinct and follow the general pattern initially evolved at Gezira, where many of Sudan's senior staff were first posted. Agricultural research for all of Sudan's schemes is handled at the national level by the Agricultural Research Corporation, which supplies its own staff to work on site at the larger schemes.

The Ministry of Agriculture in Sudan deals mainly with non-irrigation areas, since the corporations running the larger schemes employ their own extension staff and attempt to dictate what tenants may grow. In 1972, Sudan changed its local government structure to remove the shaykhs, omdas, and other dignitaries who had formerly controlled it. Because of the country's large size, there are now seven levels within the administrative system, as one moves from the local level upwards (Phillips in Bloch, et al., 1986:75). At the bottom one has village or nomads' councils, then rural councils, then district or township councils, then the People'd Popular Executive Councils at the area level, then provincial councils, and finally regional governments which deal in turn with the national government centered in Khartoum. The break between the national and regional levels is fairly complete, so that the Ministry of Agriculture does not control its functional activities in the regions but merely provides manpower to the regional governments.[1]

Gezira - At the time when the Gezira scheme officially began in 1925, Wad Medani with 30,000 people was the only urban center of any size in the whole area. Some cotton was grown on the vast clay plains for local production into rough cloth, but generally settled agriculture was confined to the islands and banks of the Blue Nile. Land away from the rivers was used seasonally by pastoralists keeping camels, sheep and goats. They would grow a quick maturing variety of sorghum (called dura) before moving back during the long dry season to assured water at the rivers (El Agraa et al., 1986).

It should be stressed that the topography was unusually favorable for the development of large-scale irrigation. The total Gezira-Managil area with linked units across the river now covers about 2.1 million feddans, taking up most of the land lying south of Khartoum between the Blue and White Niles (Figure 9). The land is almost dead level. It has a uniform landscape consisting of water retentive clay soils, which can be flooded and then left to take up the water slowly (thus minimizing the skill needed in water application). They constitute an ideal situation for gravity fed irrigation, the water being delivered to Gezira from the Blue Nile by twin major supply canals (186 and 168 cumecs capacity) which take off from either side of the Sennar Dam and flow northwards along a main ridge for 57 km before joining and then being again subdivided, with one main and three subsidiary canals serving Managil to the west and a second main canal continuing onwards for nearly 145 km through the older Gezira section, with a large number of major and minor canals branching off from it.

The main canal reaches vary in length from 6 to 22 km, and are controlled by cross regulators at about 3 km intervals to maintain upstream water at constant levels. Minor canals are designed to be used for night storage and thus are fitted with storage weirs. Ninety feddan field units (called "numbers") are each served by one tertiary canal; in Gezira proper, these are subdivided for water application by 9 laterals serving 10 feddans each, whereas in Managil (as in most of Sudan's pump schemes), a "number" contains 18 laterals serving 5 feddan field units

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[1] The situation observed in December 1984.

called "hawashas"). Gezira's water distribution system is described in detail by Ibrahim (in Fadl and Bailey, 1984). It is a highly standardized system which was made feasible mainly because of Gezira's uniform, cracking clay soils (which retain water and make lining unnecessary) and its level topography. The main change in recent decades has been the gradual takeover by tenants from "gaffirs" of control over the field outlet pipes (FOPs), accompanied by continuous (rather than day-only) irrigation necessary as the cropping system has become more diversified (though this means that water demand now exceeds supply).

The Gezira system incorporates an ingeneous solution to the problem of how to manage crops under a standard water application regime but allow each tenant a range of crops in each season. The "number" made up 90 feddans served by a tertiary canal (commonly termed an "Abu XX," for Abu Ishreen) is ideally managed under one crop as a unit. However, four adjacent numbers at any one point in time will be growing, say, cotton, wheat, groundnuts or sorghum (dura), while one will be fallow. (In Managil, as on Sudan's other large schemes, because of the lack of fallow in the rotation the sequence will be repeated in every three numbers.) Tenancy boundaries run in a narrow strip across adjacent numbers but parallel to each other, so that each tenant will have simultaneous access to cotton, wheat, dura, etc. In each "number" there are between 9 and 18 tenancies, resulting in 5-10 feddan individual fields within the larger area growing a common crop (and thus watered during the same periods). The return cycle between waterings varies between 10-14 days, and is feasible because of the high water retention of cracking clays.

Crop water requirements have been arrived at traditionally by a process known as "indenting," whereby the SGB block inspectors responsible for individual minor canals forward their estimates to the MOI sub-divisional engineers for aggregation into overall water release requirements (Farbrother in Fadl and Bailey, 1984:79). At the local level the figures given may vary widely from actual use, but when combined for large areas seem to be reasonably close to actual demand.

The scheme divides into almost equal halves, the "Gezira main" being the area nearer to the Blue Nile which was developed in phases between 1925-58, and the "Managil extension" to the west and south which was added after the revised Nile Waters Agreement of 1959 (Taha, 1975). At Gezira, tenants at first received 30 feddan holdings (12.6 ha), in three separate plots: one for cotton, one split between Luba (a leguminous fodder crop) and dura (the food staple), and one left fallow. The standard holding was increased to 40 feddans (16.8 ha) in the 1930s to permit a complex rotation using the fallow period to control cotton pests and retaining one-quarter under cotton. When Managil was added, however, its tenancies were reduced to 15 feddans (6.3 ha), eliminating the fallow but using the same crops and general system. Eventually in response to pressure from the Tenants' Union other crops were added, particularly wheat and groundnuts, as well as some vegetable growing (El Agraa, et al., 1986). From 1978-79, the main forage crop (lubia) was phased out because it was host to various cotton pests.

For over 40 years up until the 1980-81 crop season, the costs of scheme production were recovered under what was termed the "joint account" system. This meant that returns from the sale of cotton were divided in fixed proportion between the Sudanese government, the Gezira Board, and tenants as a group. Charges were assessed at a standard rate unrelated to individual tenants' use of scheme services, and the whole amount for all crops deducted from cotton returns. Since the tenants' proportion of profits was below 50 percent (up to 1971), in years when cotton prices were low tenants actually produced the crop at a loss and so had strong incentive to grow only that minimum which would allow them to continue to reside in the scheme. Official SGB survey data on cotton production in 1980-81 gave the net financial return to tenants per feddan of cotton grown at minus 3.941 Sudanese pounds, which the Board converted into a positive return by assuming 11.50 pounds would be received per feddan from the stabilization fund and tenants' household labor received payments of 20.33 pounds per feddan.[1] The Ministry of Finance and Economic Planning calculated that at average 1980-81 yields, mean private profit for extra long staple cotton was minus 45.07 per feddan and for the less labor intensive Acala cotton minus 41.22 per feddan (El-Bagir, et al., 1984:122-123). In one block surveyed in 1980-81, only 52 out of 1,198 tenants received a net profit from their cotton crop (El Agraa, et al. 1986:95).

Of course, the SGB's deduction of all its charges against only the cotton payout made the crop seem even less attractive. Throughout the 1960s and 1970s, tenants devoted more effort to their other crops; in 1975-76 and 1976-77, for example, the area planted to wheat actually exceeded that planted to cotton (see Table 25). While wheat remains popular because of its low labor requirements, yields are very low: typically, 1.4 tons per hectare (El Agraa, et al. 1986:96).

The low profitability of cotton to tenants may explain why Gezira was slow to show the benefits which might have been expected from such a large undertaking. The Gezira-Managil scheme covers today roughly one-third the surface area of Gezira Province (25,304 sq km), which in 1980 was said to contain 2,240,000 people (El Agraa, et al. 1980). Between 1950 and 1983, the number of tenants increased five fold, from 21,000 to over 100,000. To these 600-700,000 people can be added to the 150-200,000 seasonal migrants who enter the scheme each year to harvest the cotton crop; it is said there are 170,000 people living in labor camps (El Bagir, et al. 1984:104) among the 1,300 or so settlements scattered over the Gezira plain.[2] From the early days, the Gezira Board's concern with the production operations has meant that most social services were

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[1]A Tenants' Reserve Fund was set up in the 1930s to repay bad debts from the Depression, to give security for tenant loans, and to act as an equilization fund evening out price fluctuations.

[2]Taha (1975:35) estimates the total Gezira-Managil population at approximately 1,250,000 in 1975.

TABLE 25

AREA UNDER DIFFERENT CROPS AT GEZIRA

('000 of hectares)

Crop: Year:	68/69	75/76	76/77	78/79	79/80	81/82
Cotton	249	166	210	210	227	183
Wheat	69	238	212	209	158	112
Dura	135	143	148	144	113	144
Groundnuts	66	178	105	91	112	111
Rice	---	5	5	2	4	---
Lubia	53	0.6	0.3	---	---	---
Vegetables	16	10	13	11	14	18
Total (rounded)	593	742	693	667	628	568

Source: El Agraa, et al. 1986:94, from official SGB records. The total ha figures may differ slightly from column totals because of small areas devoted to other crops.

left to the people's own initiative or to the government's separate administrative hierarchy.

The SGB (as it is commonly called within Sudan) offers its agricultural services to tenants through a separate territorial hierarchy from that used by Sudan's general administration, responsible for education, health, agricultural extension, and security. The SGB divides its territory into 14 "groups" (7 each in Gezira and Managil), and these in turn into a joint total of 107 "blocks." During early years, the block inspectors and their staff "wielded great disciplinary power" (Taha, 1975:32). From 1970 onwards, however, their responsibilites were exercised through Village Councils which gave tenants some access to decisions being made about scheduling and production operations. By 1975, some 715 such councils had been set up, 483 in Gezira and 232 in Managil. The scheme's field technical staff (from group inspectors downwards) at this time numbered 520, of which the largest cadre (230) were field inspectors (Taha, 1975:33). Taha states that from the 1969-70 season tentative steps were taken to reorganize these regulatory staff into an extension service, started initially in 5 blocks and incorporating 12 (3 in Managil by 1975). The "top down" and cautious orientation of the SGB's field bureaucracy contrasts with the farmers' increasing adoption of night watering and other crops not officially part of the "Gezira system" (Barnett, 1979).

The fact is that despite its control over the livelihood of perhaps a million people, the SGB has always regarded itself as a Production organization growing cotton for the national benefit. This can be seen most clearly if one examines how the Managil extension was implemented by the SGB, developed in five phases between 1959 and 1963. The SGB's activities concentrated on extending Gezira's light railway, building staff quarters and offices, sinking tubewells ("boreholes"), expanding ginneries and warehouses, and purchasing the necessary equipment to carry out the Board's operations. Earlier plans to expand social services at the same time were cut back because of budgetary problems. Rudimentary physical planning was carried out, with larger existing villages being retained and smaller villages located in clusters at new sites. Each village was allocated between 270 and 540 feddans of land, located where possible within 5 km of where tenants would have holdings and allowing for a future 50 percent expansion (Taha quoted in El Agraa, et al., 1980:310). However, for the actual provision of services communities "had to queue up" by applying to the social development fund, which received 2 percent of the scheme's revenues through the joint accounts system (3 percent from 1968-69 onwards). Such funds were allocated on a grant-in-aid "self-help" basis, with 50 percent or more of project costs to be raised by recipients (Taha, 1975:32).

As a consequence, until recently the provision of services within the scheme area was quite uneven, with the oldest sections along the Blue Nile enjoying access to good facilities but the western, Managil sections being neglected. By 1980, there were about 500 wells dug by the Board, of which 176 had filters installed for human consumption and 50 with cholorination. The Rural Water Corporation responsible for village supplies had dug over a thousand wells, mostly on a self-help basis. However, some of Managil's water treatment plants had not been maintained for over a decade in 1980, and the town of Wad Medani had only two percent of its households with access to water sanitation--the lowest percentage out of six major Sudanese towns. A Sudanese team concluded that at Gezira "sanitation has suffered the maximum neglect" (El Agraa, et al., 1980:363).

Where Gezira has gained is in regard to hospitals and schools, the latter built initially at tenants' initiative. As of 1980, Gezira Province had 10 hospitals (second in Sudan after Khartoum Province with 17), 45 health centers, and 122 dispensaries. Of the hospital beds, 40 percent were in Wad Medani town, and only 10 percent in the whole of the Managil area (El Agraa, et al., 1980:367). In regard to schools, Gezira has the highest share in the country. There are 23 boys' and 14 girls' higher academic secondary schools (with 9 private ones each); but of the 14 girls' schools, only 1 is in Managil. At the apex is the University of Gezira, opened in 1979 at Wad Medani (El Agraa, et al. 1980:368). The "great majority" of the primary and junior secondary schools have been built by self-help, which explains the bias towards the older and richer Gezira section of the scheme area. El Bagir et al. (184:86) found that even among agricultural laborers, 53 percent were literate. By 1981, it was reported the scheme had 589 social clubs, 630 mosques, and 93 beer houses; tenants and staff owned nearly 5,000 television sets (El Agraa, et al. 1984:103). Between 1950 and 1980, then, the Gezira area emerged as the major economic hinterland for Khartoum, to which it is now connected by a paved highway.

There are official channels for tenant representation, through the Tenant's Union (with 5 tenants sitting on the SGB), but also through the Board's own Social Development Department (begun in 1950). Under it come 11 sections handling the varied activities tenants' have other than the production of official crops. These include well drilling, horticulture, animal production, forestry, cooperatives, village planning, adult education, vocational training, the "Gezira" newspaper, social research, and physical education. Several incorporate staff from relevant government departments on secondment to work with the Board in jointly implementing official programs in relation to education, health, cooperatives, animal production, local government, and housing (El Agraa, et al., 1980:354). Overall coordination of each year's program is provided by the "Gezira Local Committee," whose 20 members represent various scheme interests and the important ministries. It is chaired by the Provincial Commissioner, and has the Social Services Officer as its secretary.

The paradoxical situation which had developed by the late 1970s was that while Gezira Province seemed prosperous, individual tenants were deriving only 30 percent of their household incomes from their own tenancies (El-Bagir, et al., 1984:126). Barnett records that in Nueila villages, a tenant with a ten feddan holding would have an average net income of 107 Sudanese pounds per year from all sources (1977:76). While some tenants were undoubtedly doing well through business investments in Khartoum, relatives in civil service employment, etc., there was growing differentiation and the poorer tenants were deeply in debt and grew cotton at a loss. Even the SGB's own surveys in 1980-81 found that for medium staple cotton "the most notable feature . . . is that at low levels of productivity, i.e., for yields up to 1.5 kantars per feddan, it consumes more foreign exchange than it earns and this disadvantage is relatively greater under pump irrigation" (quoted in El-Barir, et al. 1984:128). Despite the growth of urban centers in the scheme area--admirably documented in El Agraa, et al. (1986)--the collapse of cotton production in the scheme had by 1980-81 come to threaten the entire system. Total cotton production in Sudan had almost halfed from a high point of over 550,000 tons in 1977-78 to less than 300,000 tons in 80-81, and, as we have already noted, scheme revenues covered less than one-fifth of the SGB's costs (D'Silva, 1986:5). The Board's own facilities looked almost unchanged from the 1940s, with rusting iron bridges and gates and dilapidated, colonial style bungalows.

Today, a World Bank sponsored rehabilitation scheme is underway. Cotton prices are announced at the time when picking commences, so that tenants know in advance what returns they can expect. Individually computed land and water charges have replaced the joint account system. Now tenants pay fixed charges per unit of each crop grown, varying according to crop water needs, and they are charged for the services they actually receive. These and numerous other changes which have been implemented under the Bank's conditions for its support seem to be working. In the 1984-85 season, Sudan's irrigated cotton went over 600,000 tons (D'Silva, 1986:5), and in early 1987 international cotton prices began to recover after a two-year decline.

Kenya

National Background - Kenya's total surface area of 583,000 square km puts it at roughly the same size as Madagascar or Botswana, and larger than France or Morocco. This figure is misleading. The core zone of settled agriculture in Kenya consists of a butterfly-shaped wedge of highlands on either side of the Rift Valley, which bisects the country from north to south. In length, each of the two main highland blocks stretch about 350 km, so that some 120,000 square km (just slightly larger than Malawi) would contain most of Kenya's agricultural potential, poulation, and developed infrastructure save for a narrow slice along the Indian Ocean. However, while Malawi contains 7,000,000 people, Kenya (in mid-1985) had over 20,000,000 with one of the highest growth rates (4 percent per annum) in the world. This highland core is surrounded by a doughnut of drier, agro-pastoral lands (forming parts of Narok, Kajiado, Machakos, Kitui, Embu, Meru, Laikipia, Baringo, Elgeyo Marakwet, and West Poko districts), and these in turn by a much wider belt of semi-desert extending to the Somali border in the east and to Ethiopia to the north. These outer lands contain patches of true desert, and have on average less than 400 mm of rainfall per annum making them genuinely "Sahelian" and permitting only semi-nomadic pastoral. Kenya is thus in a marked sense three countries: a central highlands populated by densely settled Kiluyu, Luo and Abaluhya peoples; a wider circle of drier, mixed farming and ranching lands populated by the Maasai, Kamba, Meru, Samburu, and Kalenjin peoples; and an outer zone of pastoral lands held by the Somali, Boran, Gabbra and Turkana.

The long-run demand for irrigation could be great, in view of Kenya's need to stabilize food supplies on its drier lands where rapid population growth is occuring, and the government's desire to generate further employment through an intensification of crop production. Access to irrigation also permits Kenya's estate sector to produce coffee for export irrespective of the varying annual rainfall--a significant national benefit. Nevertheless, Kenya makes only limited use of irrigation--a trait it shares with Uganda, Tanzania, and Malawi. FAO estimates the total area under modern irrigation in 1982 was 21,000 ha (1986:14), while Palutikof (1981) puts the 1978-79 total at 32,000 ha, of which a fourth (8,349(was under the National Irrigation Board (NIB) and some 22,000 ha on private coffee estates (supplemental sprinkler irrigation). By either estimate, Kenya's total modern irrigation is less than one might find on a single large Sudanese scheme.

The explanation lies both in the late development of irrigation schemes (not launched until the 1950s), and the different land and water relationships. Those areas of Kenya with surplus water tend to be densely settled. For example, when the NIB implemented its Ahero scheme in western Kenya, only about half the 1,000 displaced families could be reabsorbed into the scheme as tenants (Palutikof, 1981:77). Where land is readily available, water becomes very scarce (as in the huge and thinly populated areas of eastern and northern Kenya). To date, Kenya's one attempt at large-scale irrigation development--the Bura West project described below--has had to be scaled down to about one-tenth the earlier projections, though the government continues to plan for a 16,000 ha development in the Tana delta. Bura West was feasible because of a series of upstream hydroelectric dams put on the Tana River, which drains the distant eastern highlands before flowing through drier lands to the Indian Ocean. Kenya's 1979 National Master Water Plan gives the total potential of irrigable land for the Tana River Basin as 200,000 ha, with an equivalent amount for the Lake Victoria Basin; 70,000 ha in the Rift Valley's internal basins; 40,000 ha in the Athi-Tsavo Rivers drainage; and 30,000 ha in the Ewaso Ngiro drainage (figures cited Blackie, Hungwe and Rukuni, 1984:43). In fact, the Tana River with a length of 730 km, a catchment of 100,000 square km, and a mean annual flow (at Masinga) of 2.6 billion cubic meters, is by a substantial margin Kenya's largest river system; the two sites already mentioned--at Bura and in the Tana delta--constitute the best candidates for large-scale development.

There are widely diverging estimates of Kenya's irrigation potential. The government's Master Water Plan as just noted estimated it to be 540,000 ha. FAO (1986:14) puts the total at 350,000, and Palutikof (1981:78) suggests 256,000 ha. The Master Plan envisaged a steadily increasing program up to the year 2,003: to the 17,000 ha developed between 1979-83 would be added 28,000 ha in 1984-88, 42,000 ha in 1989-93, 54,000 ha in 1994-98, and 59,000 ha in 1999-2003 (Blackie, Hungwe and Rukuni, 1984:45). The Kenya Government's Sessional Paper No. 4 of 1981 on food policy reaffirmed this total of 200,000 ha to be developed within the next twenty years (Gichuki, 1986). Some advisors put the total still higher. In arguing for accelerated irrigation development, Toksoz (1981) stated that of the 800,000 ha with impeded drainage in western Kenya, 600,000 ha could be reclaimed and used for farming if subjected to a suitable mixture of flood control and drainage.

Actual achievements in adding to Kenya's irrigation have been far below projected targets. Palutikof projected that Kenya would have 58,600 ha by 1983 based on the government's own plans, derived in part from a doubling of the area under the NIB (to 17,315 ha). Instead, four years later Kenya has by FAO's estimates 21,000 ha of developed modern irrigation (1986:14). While we would put this figure nearer to Palutikof's 1978-79 estimate of 32,000 ha (because of Kenya's active estate sector involvement), this total is still well below half of what the government had anticipated by the mid 1980s.

The most obvious cause of slow development has been the capital cost constraint. Kenya's irrigation has proven to be vastly more expensive than experts predicted. Toksoz estimated the cost of Kenya's FAO assisted "ARID" schemes at US $8,000 per ha, whereas actual costs turned out to have been US $62,000 per hectare (based on unpublished FAO figures). The "large scale" Bura West project (which acordingly should evidence economies of scale) cost more than $25,000 US per ha (or US $33,000 per family) for irrigation works alone (Toksoz, 1981:15). It is said that the Wor.d Bank assisted Village Irrigation Project (VIP) implemented with Dutch technical assistance has spent some 40 million Kenya shillings, while developing approximately 164 ha to date (Arao 1986:15). Rapidly escalating investment costs have made irrigation unattainable in all but extremely favored environments like Lake Naivasha, where private growers pump lakewater to grow high value horticultural crops. The second reason for Kenya's declining interest in irrigation has been, then, the poor performance of recent projects like the schemes in Turkana or at Bura. A third and more fundamental cause is the absence of attractive sites. Those areas with surplus water (like Bura) turn out in most instances to have other major complications--as we shall see below. The Kenya Government's estimate (Table 26) that the middle and lower Tana have some 105,000 ha suited to irrigation development is probably five times too high. Similarly, while technically one could irrigate the entire Kano plain with water from Lake Victoria, this area is densely settled and the NIB encountered great political opposition in carving out the 840 ha Ahero Scheme, which has run at a loss (along with all but one of the NIB's other schemes). In such circumstances, to take engineering feasibility estimates as actual plan targets for future irrigation development gives a distorted picture. And, finally, the institutional and manpower basis for rapid irrigation development remains to be established (Gichuki, 1986).

Institutional support for irrigation has been divided between the private estates, relying upon commercial suppliers of sprinkler irrigation equipment, and public schemes which come under the sponsorship of several agencies. Arao (1986) provides a brief historical overview, and estimates that perhaps 60 percent of Kenya's total irrigation has been private, mostly on estates growing coffee, pineapples (near Thika) or other horticultural crops. This development was entirely demand led, and is described in Wright Rain (1962) and Kumar et al. (1981). The location of Kenya's estate growers in a zone marginal for coffee even though they produce 40 percent of national output makes sprinkler irrigation attractive in dry years. Palutikof states that during the brief coffee price boom in the mid 1970s many estate growers added sprinkler systems, so that by 1981 perhaps 90 percent of coffee on holdings larger than 50 ha received supplemental irrigation when needed.

Government-led irrigation development dates back to little known efforts to raise food for the troops during World War II. The Kerugoya Dried Vegetable Project was one such highly successful scheme (see Moris in Chambers and Moris, 1973), but there were others in Nyanza, such as the 28 km Agembo Canal dug along the margin of Kisumu District's Miruka Swamp (Arao, 1986). At the end of the War, government support was abruptly terminated and the projets soon faded from official memory. A second phase of activity with a focus on physical works rather than scheme operation took place under the African Land Development Board (ALDEV) established in 1945 and directed towards land rehabilitation in places like Machakos (the Yatta furrow) or lower Embu (the Ishiara irrigation scheme). The ALDEV approach with its labor-intensive construction techniques provided an apparent solution to the colonial government's need to employ landless ex-Mau Mau detainees in the late 1950s. One such project which began as a hand dug canal grew into the

TABLE 26

OFFICIAL ESTIMATES OF KENYA'S IRRIGATION POTENTIAL

River Basin	Location of Proposed Low Cost Irrigation Projects	Province	Irrigation Potential (hectares)
Nzola	Middle/Lower	Western/Nyanza	5,000
Yala	Yala Swamp	Western/Nyanza	15,000
Nyanda/Sondu/ Lake Victoria	Kano Plain	Nyanza	60,000
Gucha Migori	Lower	Nyanza	25,000
Mara	Upper	Rift Valley	20,000
Lake Victoria	Lake Margin	Western/Nyanza	20,000
Turkwel	Middle/Lower	Rift Valley	25,000
Kerio	Upper/Middle	Rift Valley	30,000
Baringo	Basin	Rift Valley	10,000
Ewaso Ng'iro(s)	Basin	Rift Valley	10,000
Naivasha	Basin	Rift Valley/ Central	10,000
Flood Spreading	Various	Rift Valley	
Athi	Upper	Central/Rift Valley/Eastern	10,000
Athi	Middle	Eastern	15,000
Sabaki	Lower	Coast	15,000
Lumi (Taveta)	Lower	Coast	9,000
Tana	Upper		100,000
Tana	Middle/Lower		105,000
Ewaso Ng'iro (N)	Upper	Central/Rift Valley/Eastern	15,000
Ewaso Ng'iro (N)	Middle	Rift Valley Eastern	15,000
Omo (Lake Turkana)		Eastern/Rift Valley	15,000
Daua		North Eastern	1,000
Flood Water Spreading	Various	Eastern/North Eastern	5,000
Total Irrigation Potential			600,000

Source: Blackie, Hungwe and Rukuni (1984:44), based on the Ministry of Water Development, 5th Development Plan (1984-1988).

Mwea Irrigation Settlement, more commonly known as the Mwea Scheme (Chambers and Moris, 1973). The early history of this scheme, Kenya's only long-term success among its public irrigation projects, has been detailed by Chambers (1969). Mwea's manager went on to design and then head the National Irrigation Board, formed in 1966 to provide supervision and technical support to Kenya's public irrigation schemes (Giglioli in Chambers and Moris 1983; Fitter, 1983).

As might have been expected, the Board promptly extended the Mwea system to the other projects it managed, including the Perkerra scheme (260 ha) in Baringo, and the Hola pilot scheme (870 ha) on the Tana River. Other schemes the NIB either built or inherited were the Ahero Scheme (840 ha), West Kano (840 ha), and the Bunyala Scheme (400 ha). By 1983, the Mwea Scheme had 5,800 ha under irrigation, making it six times larger than any other these other schemes, which have all run at a loss. The Bura West Project, located at the distant lower Tana, was to have been the NIB's first genuinely large project with 12,200 ha in the first tww phases and perhaps 250,000 ha later. Why this did not happen and instead Bura had to be taken out from under the NIB's control at presidential directive provides our case study below. First, however, it is necessary to outline the rudiments of what might be termed the "Mwea system" which the NIB has applied to all its schemes, and also the further elaboration of institutional assistance to non-NIB irrigation projects.

Fitter (1983) gives a useful summarization of the relationship of the NIB to its constituent schemes, as well as details on each scheme's comparative performance (excluding Bura West). Perhaps the central feature of the NIB's system is that the land is treated as having been vacant before scheme development. Thus the Board in developing a scheme acquires control over recruitment of settlers (officially termed tenants), who use standard size plots undr an annually renewable plot lease governed by special rules (specified in the 1966 Irrigation Act and earlier legislation). Each NIB scheme has its own manager and staff, but they hold appointments through the Board on parastatal terms rather than being civil servants. Except for Perkerra in the Rift Valley and the Tana River projects (Hola and Bura), all the schemes grow paddy (with sugarcane also at West Kano). Tenants thus retain a fixed amount of the scheme's official crop (usually paddy) in place of having a subsistence crop in the rotation. Production is highly organized by the scheme, which handles land preparation and input supply and schedules all field operations. Costs and scheme charges are debited against each tenant's account, and deducted from the payout after the scheme has handled the season's crop. Tenants also receive access to a tiny houseplot within tightly packed scheme villages, and they repay the costs of their houses under a short-term loan (originally at Mwea in three years). They farm under a welter of special conditions and restrictions in return for having a lease to between 1.3 and 1.6 ha of irrigated land. The scheme management in turn operates a fleet of tractors and keeps the water delivery system in operation. The Board employs scheme personnel, approves and processes machinery and input orders, finances buildings and infrastructure, supervises crop marketing and scheme accounts, and arranges the establishment of new schemes.

In an earlier study of Mwea Scheme, we warned that Mwea's success was based on special features which subsequent projects might not share (Chambers and Moris, 1973). Among these were the high fertility and uniformity of volcanic soils, surplus water at the required season, topography suited to gravity fed supply, an absence of claimants already settled in the area, a lack of either salinity or serious disease problems, a crop subject to controlled prices, and surplus nearby populations willing to accept the scheme's rigid system. An added advantage in the early years was that the NIB promoted its own staff as the expatriates left. (Later its top staff were nominated without regard to irrigation experience, a tremendous handicap in such a specialized organization.) While the NIB's schemes hhve not recovered their operating costs (with Mwea's tenants subsidizing the others in many years), their record has been comparatively good when compared against other Kenyan projects or similar projects elsewhere in sub-Saharan Africa. (See Table 27 overleaf giving the NIB's estimates of farm incomes on its schemes.) Furthermore, although the NIB is 20 years old it has been relatively cautious in adding staff (Table 28).

However, the NIB is only one out of several agencies which have been promoting irrigation development within Kenya. After earlier droughts, UNDP/FAO engineers became involved in assisting several small PVO schemes in northern Kenya (reviewed in chapter six). The program was at first called the "Minor Irrigation Project" and later renamed the Arid Region Irrigation Development (ARID). For ease of operational support, the small field perimeters were grouped into five clusters--for Turkana, Mandera, Isiolo, Garissa, and Tana--each with a cluster manager. Bringing in heavy equipment and salaried staff to rebuild small schemes in a dry environment was, in retrospect, a mistake; and in 1980 FAO handed its projects over to the Ministry of Agriculture (see Kortenhorst 1980, 1983; and Hogg, 1983). In Turkana, the Ministry of Energy and Regional Development through its Turkana Rehabilitation Programme (TRP) took over general supervision of the Turkana cluster projects, with NORAD providing direct technical help (Brown, 1980; Broche-Due and Storaas, 1983).

Meanwhile the Ministry of Agriculture obtained Dutch assistance to begin its own "Small-Scale Irrigation Unit" (SSIU) in 1977. The FAC/UNDP withdrawal led to expanded Ministry support and the creation of an Irrigation and Drainage Branch (IDB) within the Ministry's Land Development Division. To give more direct field assistance, the IDB operates through Provincial Irrigation Units (PIUs), which report to the Ministry's Provincial Directors of Agriculture but remain under the IDB on technical matters. At headquarters, the IDB has four specialized sections (for training, hydraulics and design, economics, and agronomy), while it intends to staff each PIU with an administrator, identification and survey section, implementation section, and extension and evaluation section. As it happens, with so many of Kenya's smaller irrigation projects in trouble, the IDB/PIU program has concentrated its initial efforts on scheme rehabilitation (Arao, 1986:11-12). The Ministry of Water also supports a few projects (such as the Yatta Furrow) and gives some design assistance on request.

TABLE 27

ESTIMATED FARM INCOMES ON NIB SCHEMES

	Gross Return/ha KL		Net Return/Farmer KL	
	1981/82	1982/83	1981/82	1982/83
Mwea	576	616	554	567
Ahero	254	360	220	256
West Kano	343	192	225	214
Bunyala	603	738	517	669
Perkerra	810	1,318	185	352
Hola	395	356	212	186
Bura	-	409	-	168
Mean	484	520	425	416

Source: Blackie, Hungwe and Rukuni (1984:35), based on NIB staff interviews.

TABLE 28

TOTAL NIB STAFF (as of June 1983)

	Senior	Junior	Subordinate	TOTAL
Head Office	35	36	19	90
Bura	11	73	11	90
Total	90	505	445	1,040

Source: Blackie, Hungwe and Rukuni (1984:35), based on NIB staff interviews.

Basically, the scale of resources field projects can expect depends more on the donor than on the Ministry. The Lower Tana Village Village Irrigation Program (LTVIP) has World Bank financing and Dutch technical assistance; the Turkana Cluster enjoys NORAD support; the former Isiolo cluster (now termed the Waso Ngiro Irrigation Cluster, or ENIC) seeks EEC help, the Garissa Irrigation Development Program (GIDP) has been promised $1.2 million (US) of DANIDA support, while the Muka Mukuu and Mitungu Irrigation Schemes in Eastern Province enjoy West German assistance. As of 1984, the main support to IDP headquarters came from the Dutch through provision of six expatriate staff (Blackie, Hungwe and Rukuni, 1984:30-31).

Finally, there are the overarching river development authorities which report to the Office of the President. The earliest established (in 1974) was the Tana and Athir River Development Authority (TARDA), with its headquarters in Nairobi; followed by the Lake Basin Development Authority (LBDA) in Kisumu and more recently the Kerio Valley Development Authority (KVDA) in Eldoret. The Bura West project comes under TARDA, which helped to coordinate planning and project preparation but not implementation (entrusted to the NIB). However, there are signs that individual river development authorities may become implementing agencies on some of the projects now on the drawing boards. In the light of the Bura experience, perhaps they should instead pay more attention to project monitoring.

<u>The Bura West Scheme</u>[1] - Bura Scheme lies on plains adjacent to the lower Tana River in a remote, hot part of eastern Kenya some 380 km by road from Mombasa and 425 km from Nairobi (Figure 10). The area receives on average between 400-500 mm of rainfall each year. Prior to development it held some 21,000 people, about 15,000 consisting of Malakote agriculturalists (sometimes termed "Pokomos") living in the riverine forests along the Tana River, and perhaps 6,000 Orma semi-nomadic pastoralists. There was virtually no infrastructure aside from a seasonal track running southwards 50 km to the district headquarters at Hola or northwards 80 km to Garissa, the nearest town. A major flood of the Tana in 1962 caused most of the farmers to move to the Tana's east bank, but subsequent 'Shifta' problems between Kenya and Somalia brought some of them back in the mid-1970s (Vainio-Mattila, 1987:28-29). To outsiders, the open bushland probably seemed virtually "empty."

The Bura Scheme (planned for 6,700 ha) was to have been the first phase of a much larger development, with Phase II encompassing 5,500 ha (also on the Tana River's west bank), and a further 25,000 ha proposed for eventual development on the east bank (Vainio-Mattila, 1987). For

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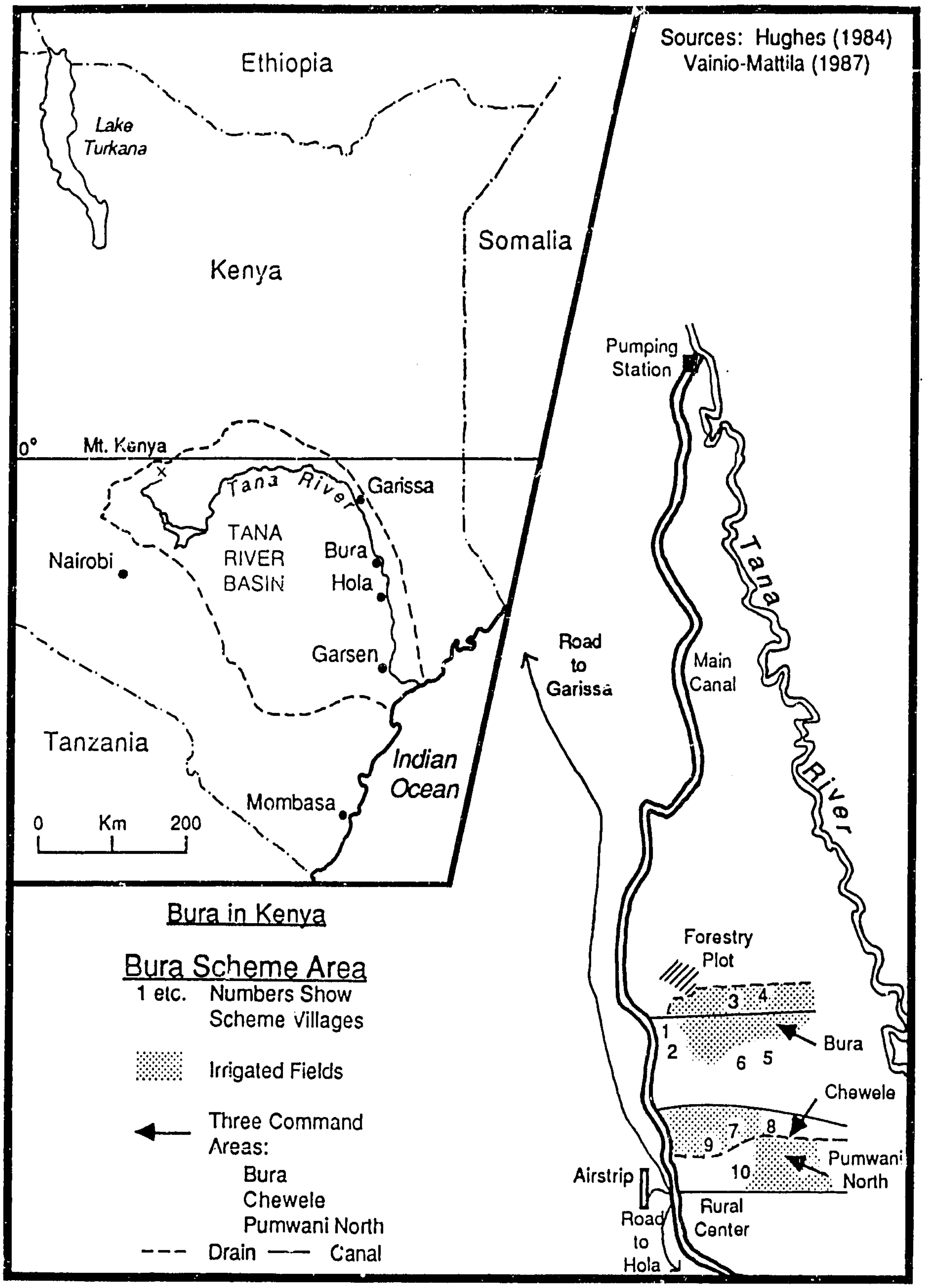
[1]Since most of the sources on Bura are restricted World Bank documents, this case is heavily based upon Gitonga (1985) and Vainio-Mattila (1987). Other published sources include Ruigu et al. (1984), Bahemuka (1983), Hughes (1984), Vainio-Mattila (1985), and Republic of Kenya (1985).

FIGURE 10

LOCATION OF KENYA'S BURA SCHEME



reasons outlined below, only 3,900 ha have been actually completed, and Bura West has become known throughout Kenya as an especially problematic project. However, it should be noted that the technical difficulties faced at Bura are typical of those encountered on many, similar projects. For irrigation planners, Bura's troubled history merits close attention.

The rationale for establishing large-scale irrigation at Bura was both technical and political. As early as 1948, the colonial government had suggested two 40,000 ha irrigation schemes might be developed somewhere along the Tana, and in subsequent studies it was proposed that a Tana River Irrigation Authority should be established to manage some 100,000 to 120,000 ha of potentially irrigable land. Kenya's large upstream investment in five major dams made downstream irrigation more attractive by bringing much of the Tana River's annual flood under control. The Bura West Project was seen as the first stage for a much larger irrigation complex which could repay the high investment costs required in developing such an isolated area. Politically, it was hoped that irrigated production would absorb landless families from the overpopulated highlands far to the west. Settlement of the scheme would increase the central government's control in an area occasionally subject to "Shifta" attacks. The official objectives were to settle landless families, to increase production of food and cotton, to save foreign exchange, and to stimulate regional development by "reclaiming" underutilized, semiarid lands (Ruigu, et al. 1984).

Planning - From the very start, the main issues were whether Bura's soils had sufficient potential to merit large-scale development, and whether a production system could be devised which would repay the high costs of establishing a major settlement "from scratch" so far from markets. The investigation of the initial colonial proposals judged in 1949 that the two schemes would be uneconomic on both counts. Nevertheless, the colonial government proceeded to establish an irrigated rice project on the east bank of the Tana near Hola in 1953, but abandoned the project four years later. In 1956-57, it started the Hola Pilot Irrigation Scheme. Hola had been built as a detention camp for Mau Mau insurgents, and detainee labor was used to construct the first 200 ha (since expanded to 870 ha).

Shortly before independence, the Kenya Government sought UNDP/FAO assistance in carrying out further exploratory studies on the Tana basin. FAO brought ILACO (International Land Development Consultants of the Netherlands) and Acres International of Canada into a joint survey team which began work in mid-1963. The eventual ILACO/ACRES report, when released in 1967, judged irrigation on the lower Tana as having marginal viability, but concluded the stabilized flow regime from upstream dams could support irrigation of some 100,000-120,000 ha (the area needed to achieve a 10 percent economic rate of return). This report is said to have called for the rehabilitation of the Hola scheme and for creation of a Tana Irrigation Authority (Gitonga, 1985:2-5). The disappointing results concerning irrigation potential in the lower Tana led the Netherlands government to indicate it would only finance further studies in the upper Tana basin, again undertaken by ILACO in 1970-71. Two feasibility studies were then carried out, one at Masinga far upstream and the other, the first, at Bura itself. This initial 1973 ILACO study envisioned a scheme of 4,000 ha based on cotton and groundnuts, with 3,000 settlers on 1.2 ha plots, and an investment cost of K shs. 23,850 per ha, or 52 million K shs. overall (Vainio-Mattila, 1987:35). On its part, the Kenya Government proceeded to create the Tana River Development Authority in 1974 (subsequently broadened to include the Athi River). Netherlands agreed it would finance further work only if donors were identified for the main project, leading to an approach to the World Bank and other potential funders.

A subsequent 1975 ILACO feasibility study raised the size of the proposed scheme to 14,000 ha. The World Bank's reservations about soil suitability led it to request further work by the Kenya Soil survey. It was decided the Project should be broken into two phases, since there was as yet insufficient information about the potential of soils east of the Tana. While this compromise allowed Project preparation to proceed in 1976, the Bank called for an independent review of ILACO's plans for the project (a bid awarded to Sir M. MacDonald and Partners and two associated firms in December of 1976). Meanwhile, there were intensive negotiations with donors in Paris (November 1976) and London (March 1977), culminating in the necessary loan credit agreements signed in June of 1977 (NIB Annual Report, 1976-77). While the World Bank's "grey cover" appraisal report was submitted in May of 1977, the loan agreements were signed before the consultants' project planning report specifying how the scheme was to be developed had been received.

While the MacDonald's report agreed on the 6,700 ha size for phase one, it proposed the weir to serve Bura West be replaced by a dam to serve both banks once the necessary survey work on Bura East was complete. In the interim, a "temporary" pumping station would be installed at the head of a 42 km supply canal until the main dam was built. It also proposed that the raised aquaducts which were to have carried the main canal over seasonal drainages (or "lagas") should be replaced by more expensive inverted siphons. Gitonga suggests that despite the reduced size of phase one and these increased costs, a 13 percent economic rate of return obtained by ILACO when assuming a 14,000 ha scheme was retained (1985:40).

All in all, these changes are said to have raised construction costs by 22 percent over what was the World Bank's own estimate for phase one. Seven donors agreed to cooperate in financing the 98.4 million dollar project. The Bank's contribution at $34 million was almost three times that of the next largest donor other than the Kenya Government itself (which pledged $20.6 million). Approval was received in time to begin work in December of 1978, although one donor (the CDC) eventually withdrew, and the plans for phase two remained incomplete. Thus, in 1978, MacDonald was again engaged by the NIB to complete the design work and to supervise construction. By the time work at site began in early 1979, project costs had increased 65 percent in real terms but no additional funding had been secured (Gitonga, 1985:12-14).

Implementation - On the NIB's earlier schemes, most of the developmental work was done internally and directly supervised from the NIB's Nairobi office. Bura was a larger and far more complex project, involving multiple donors and consultants with conflicting interests and advice. It was also an unusual situation in that work was begun before designs had been finalized and despite continuing uncertainty over the linked Bura East developments. The changes called for in the project planning report, and the NIB's own unfamiliarity in managing such a distant and complex project, were responsible for the loss of a year before actual field implementation began. By the end of 1978, just two contracts out of the more than 20 required to make the Scheme operational had been let (NIB Annual Report and Accounts 1978-1979). By the end of June 1980, only the temporary domestic water supply for the rural center and the airstrip were complete. Some of the delays arose from a "misunderstanding" between the NIB and its major donor. For example, work on the Scheme's staff houses and its buildings did not start until May of 1980 (NIB Annual Reports and Accounts 1979-1980). Others concerned unavoidable conditions at the site itself. In both 1978 and 1979, the Bura area experienced unusually heavy rains, delaying the completion of field surveys and the onset of construction. Bura had been scheduled to put the first 480 ha under cotton in March-April of 1981. It is quite remarkable that the first tenants' crops were planted within six months of the target date, but they did so within an essentially incomplete scheme.

To manage Bura, the NIB envisioned two units additional to its own internal structures. For developmental aspects, a Bura Project Coordinator's Office was set up within the NIB to liaise with other ministries and the funders. Operational aspects were to be left to the NIB itself, but it was anticipated an external management team would be required at site for the first five or six years, being understudied by Kenyan counterparts. Under a Project Manager and his deputy would come an Agricultural Manager, Project Engineer, Workshop Foreman, and Administrative Officer. Reporting to the Agricultural Manager would be five irrigation officers, one for each command; under them would come a technical assistant and several field assistants to be the main extension link to farmers (Gitonga, 1985:25). This structure, similar to what was found on other NIB schemes, is portrayed in Figure 10.

Recruitment - Going back to its origins at the Mwea Settlement (Chambers and Moris, 1973), the NIB's system has emphasized having clear criteria to guide the selection of tenants. (Kenya's overpopulation insures a ready supply of applicants.) Those recruited are supposed to meet the following criteria (Vainio-Mattila, 1987:37):

- They should be landless, and either unemployed or earning far below the average for their home area;
- The head of the household should be between 25-45 years old;
- The prospective tenant should have previous farming experience;
- Neither the tenant nor his family should have demonstrated adverse social habits;

- The tenant and family should be physically fit; and

- The household should contain the equivalent of four adult labor units.

It is NIB practice that those dispossessed to make room for an irrigation scheme should get priority in selection if they also meet the other criteria. Incoming tenants receive a one year lease, renewable annually for as long as they maintain acceptable performance (Gitonga, 1985:17). While the incoming tenant must nominate an heir, problems can arise if he dies young leaving a wife and small children who may not qualify as the official heirs. As Vainio-Mattila observes (1987:51): "Women, especially, feel left out as the households are regarded in terms of men only.

Actual details of recruitment are organized by the NIB's Settlement Officer, who helps set up selection committees in each district (chaired by the District Commissioner) and who instructs them concerning recruitment criteria. For Bura, recruitment was done nationally so that the new scheme contains people from all provinces and many districts throughout Kenya. The first 320 tenants arrived at Bura in August of 1981; by the 1982 cotton season, there were 800 tenants in place (Gitonga, 1985:27-28). The most immediate problem they faced was obtaining housing. Customarily, in NIB schemes the heads of household come in advance to a site and join a builders' brigade, which builds houses in turn for all its members under the supervision of skilled NIB workmen. At Bura, it was not to be so simple. Building materials could not be obtained locally. Timber came from the highlands over 300 km away; stone from Mombasa, 150 km away; and even building poles had to come from Lamu, also on the coast (Gitonga, 1985:39). With poor roads, Bura suffered from long delays in building and escalating costs. The Scheme's own "Bura Building Force" (or BBF) fell so far behind schedule it was eventually disbanded and the task turned over to a private contractor. By then more tenants were arriving and the work had to be rushed. Houses which had been budgeted in 1976 at between 4-6,000 K shs. cost as much as 32,000 shillings each by 1983, "raising serious doubts whether the tenant farmer will ever by able to pay for his house" (Gitonga, 1985:20). Even worse, because of shoddy construction, a substantial proportion of the houses provided for tenants under loan financing subsequently collapsed. In village 1, settled in 1982, out of 160 plots, 54 have collapsed houses; in village 3, there are 44 collapsed out of 172 plots; and in village 6, more than half out of 140 plots (Vainio-Mattila, 1987:135-145).

Production - The main crop from which costs are recovered by the Scheme is cotton, grown once in each year on tenants' two .625 ha plots at slightly different times so the planting and harvest periods will not entirely coincide. The Scheme takes the responsibility for land preparation, either using its own tractors or relying upon subcontractors, with the costs being deducted from the cotton payout. After harvest in the "short rains" tenants grow maize for their food supply on one plot, but leave their second, later plot "fallow" during December-January. This can be described as a cotton-maize/cotton-fallow rotation in alternative years, but in actual fact because cotton stays in the ground for six months and time is lost to planting and harvesting, the land is never really rested for any extended period.[1]

Irrigation is achieved at the field level by siphoning out of furrows, with a cotton crop requiring nine irrigations and three weedings in the season. Fertilizer is applied once. Immediately after cotton harvest, tenants are supposed to uproot and then burn the cotton stalks. Aerial sprayings of pesticide within each season are arranged by the Scheme management. At harvest, tenants receive a 10 percent picking advance on the money they will obtain eventually per kg of cotton sold to the Board. The picking advances are paid weekly, and while they last farmers can pay their labor, buy firewood, eat meat, and even repay debts. The balance comes in one lump sum, ideally in December, but in 1986 not received until April. A tenant's production costs in 1985 were estimated to be over 9,000 K shs. not including labor, split between fertilizers (5 bags totaling 2,122 shs.), water charges (1,000 shs per crop, totaling 3,000 shs.), and aerial spraying for cotton (2,000 shs. per crop, totaling 4,000 shs.). Average "profits" after deduction for these costs were according to the Scheme's 1984-85 Annual Report, some 3,791 shs. in the Bura command and 7,942 shs. in the Chewele command (Vanio-Matilla, 1987:49-50). Actual disposable income would be substantially lower in many instances; perhaps two-thirds of tenants hire labor at certain periods (72 percent according to Ruigu et al., 1984).

In fact, serious operational difficulties have been encountered beyond what the above average figures indicate. It took three years for the NIB to award the contract for the bulk of the Scheme's tractors. The attempt to subcontract land preparation to private operators resulted in many tenants' holdings being planted between one and two months late, causing increased pest problems, lower yields, and interference with tenants' vital food crops (Gitonga, 1985:29). There have been frequent pump breakdowns and intermittent fuel shortages. One visiting delegation in early October of 1986, shortly before farmers' maize should be planted, found only one of the Scheme's four supply pumps was operational.[2] It was noted then that "crop yield projections appeared to be significantly higher than the probable yields of the standing crops observed." In 1982-83, a drought brought about a concentration of wild game along the river and substantial damage to tenants' maize. Indeed, on a scheme supposedly established to increase food security, many tenants were being fed by their participation in food-for-work famine relief. An evaluation team from Nairobi's Institute for Development

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[1]Perhaps accounting for the rapid decline in cotton yields within the older, Bura command. The experience at Gezira where yields were very low until a longer fallow period was adopted might be relevant.

[2]"Tana and Athi River Basins of Kenya: Lessons for the Juba." Workshop on Juba Valley Development, Jacaranda Hotel, Nairobi, October 4-5, 1986 (unpublished draft report).

Studies (Ruigu et al. 1984) found that 43 percent of tenant families received income inadequate to meet their basic needs.

Social Services - The coastal areas of Kenya are notorious for having several types of malaria (including in recent years chloroquine resistant strains). Many of the new recruits came from upland districts relatively free from malaria, where social services were well established. Particularly during the hot December to February season, they experienced a high incidence of malaria which caused "many fatalities" during the nearly three years before the Scheme's health center opened (Gitonga, 1985:21). The three most widespread health problems continue to be malaria, malnutrition, and dysentery. Malnutrition is most acute before the cotton harvest when families run out of money and their maize has not yet ripened. Dysentery remains a problem because of poor sanitation in the scheme and the lack of any place where wastes can be deposited. However, the situation in regard to health facilities has greatly improved, in part through NGO actions. Today tenants have access to the Scheme's own health center (staffed by a clinician, five nurses and three nutritionists) as well as three dispensaries run by the Catholics (Vainio-Mattila, 1987:50).

Schooling, too, was delayed. The first primary school was not opened until mid-1982, a year after the first tenants arrived (Gitonga, 1985:22). Since education is highly valued in Kenya, Bura's inadequacies in comparison to upland areas must have increased the reluctance of NIB staff to accept a Bura posting, and it led some tenants to leave children and even their wives back where they had come from. It is reckoned farmers need between 3.5 and 4 labor units at peak seasons to operate their holding--a requirement which increases if the cotton is planted late so that vital tasks overlap in time. As a consequence, older children on the Scheme are pressed into performing light agricultural work and doing many household tasks, such as childcaring, firewood collection, and stove minding (Vainio-Mattila, 1987:68). Even though the primary schools are crowded, absenteeism is high at some seasons. For junior and salaried staff, the lack of a secondary school was a further strong disincentive to making Bura a permanent home.

In Kenya today, the political leadership actively discourages ethnicity. At Bura, "the basic idea is that all are tenants and now belong to Bura" (Vainio-Mattila, 1987:104). The improved stove project with which Vainio-Mattila was associated found that ethnic ties had an important but complex influence over success. By deliberate policy, all of Bura's villages have mixed ethnic membership, but in some villages one group predominates while in other membership is spread more evenly over many groups. Where a village has a single majority group, its leaders usually represent that group and others have little opportunity to participate. However, this makes it easier to organize group activities. Villages with a more even distribution between ethnic groups proved more difficult to organize. Either a more truly cooperative situation eventually emerged, or there was a breakdown of common effort "in which all groups are out for themselves" (Vainio-Mattila, 1987:105).

Sometimes ethnic ties are reinforced by religious affiliation. The local people who are incorporated in varying proportion into different villages are mostly Muslim. There are two established mosques, but numerous small churches in almost every village. Of the seven functioning women's groups, five are directly connected with the Catholic Mission. These groups carry on a range of activities, from dress-making to literacy classes. Official opinion has been that to promote cohesion each village should have only one recognized women's group. (In fact, on one village there is a cross-cultural group participated in by both the Christian and Muslim women.) It was found in the stove project that sometimes having this focus caused more women to join a given group, leading to an eventual split along ethnic lines (Vainio-Mattila 1987:106). Women also have their own, spontaneously formed working groups, usually with only four or five members.

From the above details, one can surmise that Bura's women have not found life in the Scheme's villages either pleasant or rewarding. It is especially unfortunate that such small houseplots were adopted, a carryover from the NIB's older schemes (which mostly lie in high density areas). At Bura there was ample room for a less concentrated settlement pattern, and, in any case, the infrastructure for a larger scheme was already largely in place. Twenty years ago at the NIB's Mwea Irrigation Settlement it was found that for women access to their own gardens and an adequate houseplot was vitally important to family welfare (Chambers and Moris, 1973). It was recommended then that the "Mwea System" should not be carried over, unmodified onto future NIB projects (Moris in Chambers and Moris, 1973). Unfortunately, this present account is based on the few sources which have been released into public circulation. Within Kenya, one hears of highly critical field evaluations and consultant's reports, which are reputed to have been especially concerned about the situation faced by Bura's women in the early years. As Vainio-Mattila points out, most of the non-agricultural work required to maintain tenants is carried out by women, and they also make a major contribution within the agricultural labor force (1987:69).

Scheme Management - How Bura should be managed has been a continuing point of friction between all the parties involved. In the last two years (1985-86), the Scheme has had three different managerial structures, one-third of which was instituted at presidential directive after a surprise visit to Bura on 20 January 1986 (Vainio-Mattila, 1987:45). Under the first structure (following usual NIB practice), a Project Manager was stationed at Bura but reported to the NIB in Nairobi (Figure 10). The funders were represented in Nairobi through the Bura Coordinator's office, with links also to the external project and agricultural management consultants--all coming under the NIB, though the project consultants and the contractors were of necessity also represented on site at Bura. On local matters not involving money (such as disputes over plots or houses), decision-making seems to have been adequate. But on any matter requiring NIB approval, there were difficulties:

> This is because the NIB is a highly centralized organ, with all day-to-day decision-making deferred to the General Manager, and policy-making to the Board.... In Bura it meant long delays

even in purchasing spare parts and other quite minor things; to the World Bank it meant diminished capacity to manage, not only Bura but the other schemes as well. (Vainio-Matilla, 1987:41)

The World Bank's mid-term evaluation of Bura was highly critical of the way Bura had been managed. The Scheme was running two years behind schedule, and the funds originally allocated had all been spent. As a condition for continuation of World Bank financing, it was insisted that Bura should be managed in future from site, with assistance from a World Bank management team which operated under the general guidance of a steering committee composed of prominent Kenyans (mostly located in Nairobi). To ensure complete decentralization, the Bura Coordinator's Office was directed to move to the site as well, and eventually the scheme was taken out from under the NIB to become an autonomous parastatal, the Bura Irrigation and Settlement Project (BISP), responsible directly to the Ministry of Agriculture and Livestock Development. These changes took effect in June of 1985. By the end of the year, three of the Bank's management team had arrived at Bura (an accountant, a mechanical engineer, and an irrigation engineer), but the engineers did not have counterparts and the manager was reported as having been away much of the time. The engineers "ended up taking responsibility for everyday running" while the accountants were left to sort out tenants' problems (Vainio-Mattila, 1987:45).

It can be argued that Bura's managerial problems were in considerable degree generated by the situation itself. First, Bura was the NIB's most remote project, requiring air charters for even routine visits. The communication difficulties made overt the costs which the NIB's paternalistic style of management entailed. Second, there were bound to be serious tensions when the construction schedule (supervised from Nairobi) slipped a year and then two years behind, while at the same time tenants began to arrive and production at site had to begin. Third, the NIB undoubtedly underestimated the managerial time required when dealing with external consultants and a paternalistic donor in finalizing the numerous subcontracts Bura's physical development required. Because of its remoteness and their experience of the adverse 1979 season, contractors became reluctant to tender for work at Bura, increasing costs and delays further. Fourth, the unattractivenss of life at site which depressed tenant morale also effected managerial staff, for whom the relative deprivation was even greater. With the changeover in Bura's status to an autonomous parastatal, staff feared they would become trapped permanently at Bura for the whole of their careers--a truly daunting prospect (Vainio-Mattila, 1987:45). Fifth, in this instance, the NIB was dealing with a donor which also tries to control its field projects from a great distance while meddling in operational details. Bank-imposed decisions greatly increased management's difficulties. Sixth, the crop handling parastatal had its own, major problems, which in the Bura context, left the scheme management appearing to be at fault when there were intolerable delays in paying tenants for their crops. And, lastly, the Kenya Government compounded all these difficulties by viewing managerial positions as a form of political patronage. Bura would have been difficult to govern effectively even under very experienced direction: it was an impossible assignment for those not already experienced in irrigation.

The most recent managerial structure is a complicated one. The Project Manager must deal with a steering committee (still mostly in Nairobi), a management committee (with the Provincial Commissioner as its head), and his own management team. The increased role of the provincial and district administration is also evident at the local level, where in October of 1986 the scheme's own tenant committees were merged into the general administration's village committees (Vainio-Mattila, 1987:101). Another major change in 1986 was the withdrawal of the World Bank "from further involvement in the Bura Scheme" (Vainio-Mattila, 1987:47).

Overall Performance - It is important when reviewing Bura's experience to acknowledge that the Scheme would have encountered serious operational difficulties even if it had enjoyed excellent management and highly committed support from the NIB. Arguments to support this conclusion are as follows:

First, at its reduced size of 3,900 ha with 3,000 tenants, even with good yields the project will incur annual operation deficits of around K shs. 38 million on its agricultural operations, plus a further 7 million for its social services (Gitonga, 1985:34). Tenant incomes are already lower than the Scheme's somewhat optimistic budgets assume, so there is no scope for increasing service charges to reduce the deficit.

Second, the Scheme's dependence on an unreliable pumping station located far from its main operational base makes it subject to breakdowns and delays which immediately and directly depress output. While a gravity fed system (as initially designed by ILACO) might have been more expensive, it would not have left the Scheme so vulnerable to supply disruptions.

Third, at Bura (as in the NIB's projects generally) timely planting, which is required for good yields, depends upon a synchronized movement of tractors throughout the scheme area. As at Mwea (Chambers and Moris, 1973), it is this aspect rather than water delivery per se which imposes severe scheduling stress upon the managerial system. In an area with "black cotton" clay soils and poor roads, it becomes very difficult to work the land when heavy rainfall is experienced. At such sites, timely centralized land preparation will always be problematic.

Fourth, Bura has suffered from the weak performance of other agencies--public and private--within its immediate environment. The Ministry of Health's delay in providing medical services for tenants and the Cotton Board's failure to pay farmers are two examples, but Bura has also received very poor service from some private contractors.

Fifth, the system of deducting costs irrespective of the quality of performance leaves tenants to absorb the losses when delays occur. We have argued that tenant households at Bura had no cushion to carry them over if yields were greatly below expectation or payments delayed.

Traditional Irrigation

Introduction

Indigenous, small-scale irrigation has a long history in various parts of tropical Africa. Hints of an earlier irrigation tradition come from an archaeological site at Engaruka in northern Tanzania, and from relic terraces found on the Jebel Marra massif in western Sudan (Grove, 1970:88). Over much of Sudan and West Africa, small oasis wells using a shaduf for water lifting are found, while north of the Sahara are Persian style qanats, horizontal galleries cut back into mountainsides to reach an aquifer. In the "qoz" sands of north central Sudan and around Tombouctou in Mali, traditional irrigation on the borderlands of the Sahara was once quite important. Along major rivers like the Niger, the Senegal, and the Nile, African farmers have for centuries grown sorghum, millet, and perhaps rice under a form of "flood recession" (or décrue) irrigation. As already noted, the fact that the varieties of rice traditionally grown in Africa (Oryza glaberrima) are of a different species from the Asian types (Oryza sativa) supports the conclusion that African varieties were domesticated locally, possibly in the borderlands of the Sahel (Harlan, 1975). Along the West African coast from Liberia northward to southern Senegal farmers developed indigenous forms of swamp-rice cultivation. In East Africa, the surviving systems depend upon locally constructed and maintained furrows seen in Kenya's Kerio Valley and among the Sonjo of northern Tanzania (the two best documented instances), but also found among the Chagga on Mt. Kilimanjaro, the Taita living nearby in Kenya, and in the Pare and Usambara Mountains. In all of these instances, the technologies employed are quite simple even though the resulting system may show complex adaptations to suit local environments (Richards, 1985). Finally, one should note the traditional wet rice irrigation found in the highlands of Madagascar, with strong cultural and historical links to southeast Asia.

Until recently, no attention was paid to these types of traditional irrigation by irrigation specialists. The tiny plots and very crude technologies were not taken seriously by engineers and planners, who sometimes had a stake in establishing that riverine lands were "unused" and unproductive. The complete absence of reliable information on the spatial extent of traditional irrigation makes it difficult for planners even today, when the contribution of indigenous systems to food production is becoming more recognized. The figures given in official documents are mere guesses. For example, in Nigeria Maurya and Sachan (working in Zaria's Institute for Agricultural Research) state the total number of hectares devoted to "fadama" small-scale production is 26,356 ha (1985:275). FAO, drawing upon the World Bank's earlier 1979 agricultural sector estimates, puts this total at 800,000 ha (1986:14). Even among well informed observers the estimate may vary by as much as 300,000 ha, equivalent conservatively to the livelihood of some 1.5 million people.

There are good reasons for paying closer attention to Africa's traditional irrigation at present. The most compelling are related to the construction of dams in Mali, Nigeria and Kenya (and others planned for Ethiopia and Somalia) which permanently alter the downstream flood upon which traditional flood recession farming depended. It seems only reasonable that planners, at the least, should know how much production they are displacing before new large projects are built. On the Senegal River, an artificial flood is to be provided by water releases from the Manantali dam (upstream on the Bafing River in Mali), but for this tactic to be effective, a great deal must be learned about downstream décrue cultivation. More generally, there is the argument that indigenous technologies, simple as they may appear to be, for this reason require far less capital than do modern ones, and the crops likely to be grown under them may be more effective in relieving food shortages. The spontaneous expansion of such technologies under conditions of population growth in places like northern Nigeria or the valley-bottom lands of Rwanda and Burundi suggest that this is the case. Another imponderable is the effect of spontaneous modernization upon existing small-scale irrigation. What would be the impact, for example, of importing a large number of cheap pumps (a matter recently at issue in Niger)?

Finally, there is the possibility that indigenous social institutions might be given responsibilities for small- and medium-sized modern systems in an effort to reduce the managerial load carried by irrigation agencies. The widely reported "success" of the Philippine National Irrigation Administration's devolution of some functions upon local water user associations is seen as setting a useful precedent for Africa to follow. Are there in Africa traditional institutions which might be cheaper and more effective in operating small-scale irrigation systems? To answer this question requires detailed knowledge of existing practices beyond what has been available to date when irrigation projects were being planned (Mock 1985).

Oasis Irrigation (Sahara desert)

While peripheral to this report's main concentration on sub-Saharan Africa, the topic of oasis irrigation does provide an instructive example of the fragility of traditional systems under changed economic or ecological circumstances. It might be noted the oases on the Sahara's northern edge depended on large part for water derived from "qanats" (locally termed "foggaras"), upslope, horizontally driven tunnels which tap groundwater from a mountain range. Apparently brought into North Africa from Persia during the Arab invasions of the ninth century, these structures provided water for the larger oases in southern Algeria and southern Morocco. They represented a large commitment of labor during original construction, and must be repeatedly cleaned to continue in operation. While some are still important on the Cape Verde Islands (Stutler, personal communication), in North Africa "there are numerous 'dead qanats'" (Nir, 1974:66). Various reasons can be given for their decline--advance of dunes, falling groundwater table, abandonment of the oases--but a main cause was the necessity of having access to cheap labor for maintenance:

> The construction...and their maintenance was a collective enterprise; the qanat belonged to a group of owners, who took care of it and used part of its water; the work was done by

> slaves. The French administration abolished slavery; the slaves became hired laborers; the qanat owners were faced with expenses they had not incurred before. The qanat, instead of being a collective enterprise, became the property of those who had money to buy a share in it; thus, the falahs who did not possess enough money to buy a share became tenants of the qanat owners. Those who had no lands abandoned the oasis. In many cases the qanat is not worth its expensive upkeep, deteriorates and is abandoned. (Nir, 1976:66)

It appears that the atrophy of oasis production north of the Sahara extends southwards, where a matching decline has taken place. Authors examining this phenomenon include Nesson et al. (1973), and Wilkinson (1978). Many oases depended on date production, utilizing poor quality water. With a decline in demand and high transport costs, today most have become "fossil settlements" which are unattractive except where for reasons of governmental control outside financial support is interjected into the local system. Those oases still functioning depend on pumps, with many disputes arising over access to water and the emergence of new forms of distribution (Fauchon, 1980; Nesson et al. 1973; Allan, 1976). Trade into "black" Africa has also atrophied with a collapse in the demand for salt blocks which were formerly carried by camel caravan to pastoral communities and farmers living on salt deficient lands far to the south.

Swamp Rice

The coastal areas of West Africa from Senegal southwards through Liberia receive more than 2,000 mm of rainfall per annum and have developed their own indigenous traditions of rice production (Rydzewiki, 1984; Pearson et al. 1981; Dey, 1984; Richards, 1985). It is not usual to think of the high rainfall zone of Africa's humid tropics as requiring irrigation, but in fact during the four months of dry season rice does require supplemental water if it is to be grown, either out of season according to local practice or under a more intensive two-cycle regime as recommended by some development projects. The literature has come to refer to all such instances as "swamp rice" production in contrast to "upland" rice grown under shifting cultivation, which does not employ any form of irrigation. There are now several detailed studies of indigenous West African rice production in addition to those cited above (Are, 1975; Linares 1981; Njoku, 1971; Richard, 1986; Spencer, 1981; and Traverse, 1975). The article by Johnny, Karimu and Richards (1981) is especially important, and underlies what will be said below.

The technical feasibility of "swamp rice" cultivation arises because of the peculiar, undulating terrain found along the coast of Sierra Leone and its neighboring states. In places the land has become submerged into the sea, proving "drowned" valleys where the rivers entering the ocean provide an ideal environment for the formation of mangrove swamps. Farther inland, numerous small hills have hundreds of winding depressions between them. In Sierra Leone's Northern Project area (site of a World Bank assisted integrated agricultural development project, or IADP), for example, it is estimated there are about 1,500 such swamps totaling perhaps 6,000 hectares.

A typical swamp is from 60 to 100 meters wide, and of varying length. The ones most attractive for cultivation tend to be between 400 and 800 m long and have an area in the range of from 2-4 ha. Clay soils are found because the valley bottoms are very flat and hence have impeded drainage. However, there are usually underlying gravels or sands and the clay topsoil may be quite thin (Rydzewski, 1984). Indeed, on one of the IADP's demonstration swamps to convince farmers of the benefits of more systematic bunding, a drainage channel was inadvertently cut through the clay "with results...not unlike pulling the plug out of a bath" (Richards, 1986:22). The aim is to improve water control and drainage in such swamps by subdividing the central area into flat fields suited to wet rice production. This is achieved by constructing perimeter ditches and bunds, and usually a central drainage ditch with bunds on either side. Where clay soils are very thin, the bunds must follow the contour, but engineers prefer rectangular bunds to facilitate access for equipment. It has been found that for individual farmers, plots of about a tenth of a hectare are all that they can manage with typical labor resources (Rydzewski, 1984). Having urged farmers to work jointly in making these improvements in the first year, assuming about 290 man-days per hectare, the IADP plan was that farmers would level their plots and install inlet pipes from the perimeter ditches to achieve a substantially improved degree of control over water levels in their rice paddies. Such "improved" swamp systems built under World Bank supplied farm loans can be contrasted with farmers' indigenous development of their own forms of swamp rice cultivation, which they prefer to combine with upland rice farming in a ratio of two-thirds upland rice to one-third indigenous swamp cultivation (Richards, 1986:25). A further difference was that initially the IADP plan called for double cycle cropping of shorter duration rice varieties where swamps had sufficient water to make this feasible. In some of the "improved" projects, an attempt was also made to introduce Asian wet rice varieties in the mistaken hope that these might out-yield existing cultivars.

The term "swamp rice" cultivation thus encompasses at least four different types which are all labor intensive alternatives to upland rice growing. The two indigenous versions--upland valley farming and coastal mangrove swamp clearing--have been matched by modern adaptations which entail increased physical construction and sometimes different rice varieties. As Richards (1985, 1986) points out, the rationale for extending loan financing to facilitate "improved" systems was based on two false assumptions: 1) that land for production was more limiting than labor; and 2) that the intensive, valley bottom production of wet rice was more efficient and profitable than farmers' alternatives.

Johnny, Karimu and Richards (1981) argue that among Sierra Leone's farmers, the advantages of swamp cultivation are recognized but balanced by an accurate appreciation of less desirable features. On the positive side, swamp rice is obviously less subject to rainfall uncertainty. In 1973, for example, rainfall was 40 percent below average in the eastern and northwestern parts of the country. Within a season, farmers doing swamp cultivation are less tightly bound by timing decisions than are those who grow upland rice--an advantage to households short of labor such as those with children in school or doing agriculture on a part time basis (teachers and businessmen). However, only a few swamps are situated where they receive water throughout the year. Most dry out seasonally, and are "very carefully broken down into component soil and moisture facets, with farmers choosing rice varieties appropriate to each set of conditions" (Johnny, Karimu and Richards, 1981:599).

On the negative side, swamp cultivation requires a high initial input of labor (roughly equivalent to one season's work); the varieties of rice grown are less palatable and less easily sold; sickness is much greater for those living near the swamps; the work itself, while more flexible as to timing, is harder and more uncomfortable; and if two cycle cropping is attempted, one crop will mature in cloudy and wet weather making harvesting and storage very difficult. Swamp farming obligates households to specialized mono-cropping of rice, whereas in upland farms rice is intercropped with a range of other food and cash crops. The differences in mean yields are not as great as the proponents of "improved" systems claimed, both because yields from the intercropped upland system were underestimated but also because, ironically, there has been a high failure rate from the supposedly more secure swamp rice projects. Richards summarizes the results from numerous recent evaluations on the attempted transfer of the "Asian model":

> Many swamps quickly dry out when the rains cease, and the promised benefit of double cropping proves to be unattainable. Design, layout and construction work is often carried out to inadequate standards. Surveyors and extension workers frequently give farmers inappropriate advice on the location or size of the head bund.... Swamps with insufficient water flow are vulnerable to a number of soil management problems, including iron toxicity.
>
> Farmers...frequently find that their yields drop below those achieved by local management practices without water control. Abandonment rates for developed swamps are high, and recovery of swamp loans is, not surprisingly, then very difficult. (Richards, 1986:33)

Owen (1973) suggests that swamp cultivation exposes farmers to heavy weed infestation, so that the women who used swamps generally abandoned their small plots after a few seasons to start afresh elsewhere.

In point of fact, swamp cultivation is traditionally a woman's enterprise, undertaken on very small plots to supplement household food and income (Dey, 1984). Of the 45 women farmers interviewed in the Johnny, Karimu and Richards' study, 32 cultivated swamp rice and only two--both widows--had upland rice farms. Women in Sierra Leone find it difficult to undertake the complex negotiations to obtain land for upland farming, and much of their interest is to produce crops for cash sale to give them an independent income. None of the men in an earlier 1978 village survey cultivated in a swamp, even though land was available, and none applied the Mende term <u>kpaa</u> (or "farm") to cultivated swamp.

Finally, in 1980, a group of farmers joined together to clear a swamp for planting an improved rice variety, but their activity was viewed strictly as a business venture separate from their normal household farming. When several years earlier a prominent chief had organized communal labor for swamp improvement in response to government exhortation, "the work was pursued in desultory fashion...and was subsequently abandoned" (Johnny, Karimu and Richards, 1981:603). The authors conclude:

> Most farmers were aware that government wanted to encourage swamp work. The plight of urban workers evoked little sympathy. Several times it was suggested that if food in Freetown was short arrangements might be made to ship some of the labour force back to the countryside.

Official attempts to upgrade swamp cultivation through offering externally-backed loan financing have been, it would seem, premature. First, double cropping of Asian rice varieties (assumed in project appraisal) has not been successful: local varieties continue to outperform introduced ones (Richards, 1986:131-155). Second, women who knew the most about traditional rice cultivation have usually been bypassed in the allocation of loans and plot rights (Dey, 1985:435). Third, the "improved swamp rice" option (or "package") was treated as a general solution to the problem of "overpopulation." In actuality, the farming systems are often short of labor, and the "package" suits only certain types of producers in particular resource situations. Fourth, valley bottom and mangrove swamp settings require unusually careful land preparation if their productive potential is to be retained. When building soil bunds and drainage ditches in shallow clay soils, swamp rice projects sometimes destroyed the water holding capacity of the very areas they were trying to "improve." And, fifth, it seems that the high iron and aluminum content of many West African soils pose a special danger when land is drained to permit more intensive production. IITA's experiments in Nigeria found that a rapid depletion of micronutrients made plants much more susceptible to ferric and aluminum toxicity as soil acidity increased (1984:123). It is said that on some of the "improved" mangrove swamp projects, a similar process rendered fields completely sterile after a few seasons.

Taita Hills (SE Kenya)[1]

Kenya's Taita Hills which rise abruptly to about 2,000 m from out of the coastal plains are densely populated. Farmers attempt to obtain plots on which to grow their staple crops of maize and beans in the three ecological zones recognized as one moves from the cool uplands down onto the surrounding plains. Along the sides of streams which descend rapidly from the forests above are grown sweet potatoes, taro, yams, bananas, cassava, and even rice. In the upland, cool zone, "European" vegetables and coffee are the major cash crops.

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[1]This account is based entirely upon Fleuret (1985), who did fieldwork in Taita/Taveta District from January 1981 to May 1982.

Like most of their neighbors, the Taita people were organized traditionally on the basis of clans and lineages. One's residence depends either upon marriage or one's membership in a "great lineage" +which controls access to land, grazing rights, and residence in a strip of territory which preferably stretches across the three major zones. In each locality or neighborhood will be found two or more "great lineages" which divide into smaller patrilineages and these ultimately into exogamous small lineages within which genealogical links between members can be explicitly traced. Status differences based on gender, age, and generation are also important, with particular deference being accorded to one's grandfathers, fathers, father's brothers, and elder brothers. Such people, are expected to assist in acquiring land and becoming married.

Boundaries of neighborhoods coincide roughly with those of sublocations, under an administratively appointed sub-chief. Access to land, except for those purchasing it (usually either the rich or salaried staff), depends upon one's inherited lineage membership or upon marriage. Because of severe overcrowding in the highland zone there has been a movement in recent years of younger men out onto the surrounding plains. In the hills, land is still associated with lineage membership even though in parts of the area land registration has been completed. The fact that access to land depends on kinship means that the land registers are soon outmoded by subsequent, unrecorded land transfers. While buying and selling of land is infrequent, land is often loaned temporarily between agnatic and affinal kin.

In this setting, furrow irrigation has been practiced for many generations, and it seems the irrigation works may have been more extensive and better maintained during the precolonial era than they are today. The system Fleuret describes occurs in the upper reaches of the Mwatate River, which flows through a steeply banked gorge. Within less than three kilometers some 16 furrows take diverted water along the contour to farmers' fields. The intakes are constructed of sticks, rocks and earth in the tailwaters of small pools formed as the river tumbles down its gorge. The intakes are repaired each year after the heaviest rains are over; the temporary nature of the intakes protects the furrows, which are dug into the slopes and built up at places where they must skirt large rocks. Furrows are less than a meter wide and about a foot deep, with footpaths along their narrow banks giving access to adjacent fields.

Customarily, those on a furrow get water in turn for a 12-hour stretch (midday to midnight or midnight to midday), starting with fields nearest the intake and then progressing down the furrow to its end before again returning to the intake. At the upper end with its stronger flow, two fields can be irrigated at a time, while there may be little water left by the time "tailenders" receive their turn. Similarly, the communal rehabilitation at the start of the irrigation season begins from the top and will involve half a dozen users or so in sequence as the furrow is brought back into operation. Water application is achieved by the simple expedient of digging a gap into the furrow wall on its downslope side, and then putting in a rock to divert the flow. Farmers exercise considerable ingenuity in guiding the water through their fields by hand, creating temporary channels as required. While small fields are served by a single outlet, larger fields may require six or seven. When the irrigation period is over, the farmer rebuilds the bank and removes the stone--a task his downstream neighbor will do if he should forget.

The principal use of furrow water is to extend the growing season, both during the "long rains" (March to June) and the "short rains" (October to December). If in either season the rains stop early, furrow irrigation is vital to carry the growing crops through to maturity. It takes a great deal of work to prepare a furrow for irrigation, so in years of heavy rainfall the system is not employed. Maize, beans, and sweet potatoes are the main irrigated crops, though higher up some commercial vegetable production occurs. After harvest, water can be diverted to other purposes such as irrigating pastures or serving livestock (otherwise taken to water in the valley bottoms by children). Since houses are often built at the foot of irrigated fields, many farmers will open a small tertiary furrow only a few inches wide to serve household needs. During the driest parts of the year, livestock are supposed to be given preferential access to the little water that remains. Of course, this benefits mostly the senior men in a lineage, who own most of the livestock.

Routine "water management" is thus mainly seeing that each furrows are reconditioned at the start of each irrigation season, encouraging users to keep their sections maintained, and deciding upon water allocation when water is scarce. The basic rule is that work is done by the potential beneficiaries. Unlike in other agricultural tasks, furrow cleaning and repairs are done by men rather than women; and men also organize the meetings where decisions are reached. Each main furrow has its own committee with an elected chairman and representatives from the principal lineages using the water. The committee sets the days for furrow maintenance, and if necessary assesses fines upon those who shirk their duty or who infringe upon a neighbor's water turn. However, since people live near their relatives most water disputes are resolved by senior kinsmen without taking the matter to the furrow committee. Public disputes are more common between upstream and downstream furrow users sharing a common source, since upstream withdrawals to support year-round vegetable production have increased and there is now insufficient water to meet demand. Such disputes go to the sub-chief for adjudication, or even to the chief if the two furrows lie within different sub-locations.

In his analysis, Fleuret stresses that the kinship ties linking users are of central importance to explain the smooth operation of the furrows. Where water relationships are an epiphenomenon of pre-existing social relationships, it takes little apparent effort to operate the system. There are few purchased items required--a little cement perhaps for repairs or an intake foundation--and the problems which arise can be resolved within the framework of multipurpose local institutions which were not created specifically for water management. The furrow committees work because their members are friends, neighbors, and kinsmen. Whether such bodies would be equally effective in operating introduced systems with major water control structures and a need for continuing cash inputs is doubtful. Even "small-scale" expert designed systems would probably ignore the multiple uses of water in the present system, while leading to a loss of local autonomy as new organizational features are imposed from above. The Taita furrows have supported vegetable production for over forty years because they did not entail such changes for their operation.

Marakwet (Kenya, Kerio Valley)

Pokot - Among the Marakwet and Pokot peoples on the west side of Kenya's Rift Valley, particularly along the very steep Elgeyo escarpment, farmers have long depended upon furrow irrigation. Within a 40 km stretch of the escarpment, there are some 40 main irrigation furrows, totaling about 250 km in length, with the largest being up to 14 km long and descending over 1400 m (Soper 1983). While this system goes back to pre-colonial times, it has been described in detail only quite recently through the work of Ssennyonga and others.[1]

The Marakwet furrows seem deceptively simple, based upon permeable weirs built across fast flowing streams as they come off the escarpment to channel water into diversion furrows only 60-90 cm wide. The combination of rudimentary construction and steep initial gradients imposes an effective limit to a furrow's flow capacity of between 150 to 200 liters per second (Soper, 1983). On the larger streams, there may be four or five parallel offtake furrows, crossing and recrossing each other as they descend along the steep slopes. A narrowed section near the off-take weir is usually provided to act as a sluice, which can be closed off with rocks and brush to protect the furrow during times of heavy flow in the source stream. The areas eventually commanded from a single furrow range from 270 to 725 ha, and occur on benches along the escarpment or on the pediment slopes below. Most of the furrows are steep in their upper portions (e.g., the Karel furrow which drops 80-90 m in 1 km), but become much flatter lower down where they reach farmers' fields. At points a furrow may be carried across a rock face, flowing along a platform built up of tree trunks and branches; where there is a steep gradient it may be lined with rocks or a natural watercourse used; and in a few instances furrows are employed to augment water in existing streams. While some furrows are said to have been already in place when the Marakwet people arrived, much of the construction is fairly recent and reflects efforts by different clans to obtain a more assured water supply for their crops and animals. The furrows must be maintained constantly, since during heavy rains they become clogged with mud and sand and the locally-built construction requires frequent repairs. Nevertheless, since the furrows depend entirely upon gravity and local materials, they require no external input beyond what villagers can themselves supply.

Where water is plentiful, each furrow is owned and maintained by a single clan, but where water is scarce up to six clan sections may have been involved in its construction. Only two of the streams provide

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[1]See contributions by Soper and Ssennyonga in Kipkorir, et al. (eds.) Kerio Valley (1983) and Ssennyonga (1986).

enough water for simultaneous use of all their furrows. Otherwise, and in the dry season, the smaller streams can supply only one or two furrows at a reduced flow, and then the distribution can become quite complicated (Soper, 1983:89-92). It is customary to open furrows to allow a small flow during part of each day for domestic use, termed "water for goats." On shared furrows, clans may take turns for a year at a time in obtaining access. For example, the Kabarmwar furrow is owned by the Kabarmwar and Karmariny clans who cooperated in its construction. In 1980, when the Karmariny had the right of use, some water was let down the Kabarmwar side each day from 3-6 p.m. for domestic use. In Mokorro Location, served only by two small streams, village groups take their turns, in every year about half do without. Here the water is so scarce the plots have become strips a few yards wide and between sixty and a hundred yards long. As a rule, furrow water is employed to supplement and stabilise rainfed cultivation: fields are saturated at the time of planting, and then as rainfall tapers off continue to receive furrow water until crops are mature. The major inefficiencies which have been observed derive from conveyance losses where soils are more porous and from an individual farmer's inability to adequately use water as it flows across a field, sometimes with considerable velocity because of the slope. The size of the areas being irrigated depend obviously upon the capacity of the furrow and its length: the people of Endo who had the largest supply also had the largest fields; and one field might receive water for a whole week at a stretch.

How scarce water is allocated and the furrows maintained has been studied by Ssennyonga (1983, 1986). The four groups living in the Kerio valley--the Pokot, Marakwet, Keiyo and Tugen--all speak Kalenjin dialects but were organized traditionally under patrilineal clans which operated through neighborhood councils rather than centralized authority. Those who construct a furrow are thought to own it, ownership being by named corporate groups which are either clans or sub-sections (lineages) of a clan. The farther a clan's territory from a water source, the greater the effort required to gain access to water. A long furrow might be jointly constructed by several clans, and even in a few cases by "landless" clans who negotiate from a distance to obtain some access to land and water. Individuals acquire specific rights to withdraw water when a furrow passes near their fields. Since people live on lands obtained from their patrilineal relatives, "there is no water bureaucracy nor does one have to seek permission or even to notify anybody else in order to get irrigation water" (Ssennyonga, 1983:105).

Those using a furrow meet once a month or so to work out the distribution schedule, except at times like the heavy rains when there is no need. When water is ample, each locality along a furrow gains access to its water for about a week at a stretch, with individuals often being given uninterrupted access for six hours during the day or throughout the night. Closing or opening a furrow at the diversion point is done by stones or logs in accordance with the agreed schedule. A green branch beside the diversion may signify it is open and should not be tampered with; each user does the cleaning and opening and closing for the supply to his or her fields. People take these arrangements seriously, either attending the meetings where the turns are decided or making sure to have someone to report back what was decided.

When needed, canal cleaning is done by all users on an agreed day. There may be more elaborate arrangements on the jointly owned canals. In one case, the clans along the furrow do the regular checking and maintenance but expect to participate in any ceremonies carried out by the other group. Ad hoc repairs are called for at the time when noticed, usually by the person appointed to do the routine check who gives a loud shout taken up by neighbors until a repair group is mobilized. For the repair of major damages, some clans have "blowers" who live at strategic sites and will blow special horns to spread the warning from one blower to the next over an extended distance (Ssennyonga, 1983:106).

In summary, then, Ssennyonga identifies five tasks which were provided in the local social system to facilitate furrow operation:

1. Routine inspection;
2. Monitoring and regulating water level and flow;
3. Opening and closing the diversion points;
4. Cleaning; and
5. Repairs.

It is significant that conflict is not identified in this listing. Ssennyonga argues that the clan leaders resolved conflicts in their traditional council (Kokwo) meetings. There appeared to be few conflicts between users, but an emerging area of potential conflict caused by the intervention of externally appointed government agents and by ambitious higher level plans for the development of the Kerio Valley. Here the fact the system was studied by Soper and Ssennyonga before major developments had been implemented provides a valuable baseline for analyzing subsequent changes.

Already by 1980 major changes were in the offing. First, the Kenya Fluorspar mines at Kimwarer were alleged to have polluted the Kerio River at source, making its water "unfit not only for human and animal consumption but also irrigation" (Ssennyonga, 1983:100). While this would not have affected the water diverted from the smaller rivers coming off the escarpment, it may have made people more dependent upon them. (Fluorspar occurs in commercially viable quantities throughout much of the valley.) Second, intensified settlement with attendant loss of forest and exposure of slopes in the upper zone feeding each river has reduced furrow yields, both because of there being less water and because of increased saltation. Third, the authority of the clan leaders' councils (kokwo) has been effectively eroded by the interposition of chiefs and sub-chiefs into the local political system. Today it is the appointed subchief "who takes the people's problems to the higher levels and articulates their needs" (Ssennyonga, 1983:107). Fourth, the Ministry of Agriculture has entered with its own plans for an officially sponsored irrigation scheme at Tot; there is equally wide scope afforded by the terrain for introduction of hydropower installations. And, fifth, the Kenya Government created the Kerio Development Authority in 1979 to coordinate development planning throughout the entire valley. Even at that time it was obvious that better roads would be required, bringing the Kerio Valley into the mainstream of Kenya's tourism and mineral development. Soper (1983) warns that the apparently minor structures such as embankments and drainage ditches required for a highway could have major negative impacts on the many furrows it would cross.

The transition from a locally built and controlled system to one which depends upon external initiative and support is perhaps inevitable. Ssennyonga gives as an example the role of the assistant chief at Arror in raising funds to repair the Kapkamak furrow (Ssennyonga, 1983:107). Soper notes that this furrow contained a stretch of about 50 m which had a serious break in January 1980. Through intervention of the sub-chief, its repair became a "Harambee project" whereby all males in the sublocation were required to pay two or three shillings, and those working outside ten to fifteen shillings. The money raised bought pipes, cement, and the skilled work to build a masonry wall 10 m long and 2 m high. The project was judged a great success, but at the same time represented a significant step away from clan-based initiative. In this instance, the precedent may be quite important, since there is another nearby furrow which was dug for some five kilometers before being abandoned:

> Its effective length is now less than a kilometer, the small flow serving the domestic needs of the Kapchebar area. The wasted labour investment in this furrow is appalling, though the dynamic sub-chief of Arror has plans for resuscitating it. The main reason for the failure, however, appears to be the rather sandy, largely decomposed gneiss bed-rock through which large stretches of it are cut.... (Soper, 1983:83)

One can foresee that a lined, cement canal would solve the problem and provide output from a substantial local effort. At the same time, to realize this relatively minor technical intervention would mean involving outside experts and higher level officialdom. As Ssennyonga asks:

> Will the people lose their sense of initiative and instead adopt an attitude of dependence? And yet without cooperation at a level larger than the clan unit it is not easy to exploit the economies of scale especially in the context of increased water demands. (SSennyonga 1983:107)

<u>The Pare Mountains.</u> (NE Tanzania)

Looking at traditional irrigation along three rivers in Tanzania's Pare Mountains (which face across open plains towards the distant Taita hills), Yoshida (1985) found many of the furrows had been dug more than 100 years ago and were owned by specific plans associated with their construction. In the upper area near the forest there were also found collecting pools, roughly five by ten meters in size, and named after the person who had built the pool (also more than a century earlier). These collect water from a spring or nearby stream for release during daylight hours down a small furrow (Yoshida, 1985:51). However, the larger furrows occur at various points along each river's drainage as it drops rapidly towards the plains below. The water is used for irrigating crops, watering livestock, and making bricks. It allows cultivation of maize, beans, vegetables, sugarcane and cardamom during the dry season, but is of equally great importance to insure that crops planted in the "short rains" (October-December) can be brought to maturity. These days people try to have separate sources for drinking water because of contamination of furrow water by insecticides used on the coffee. Lower down, there are also some places where furrow water permits irrigated rice growing (Yoshida, 1985:53).

The responsibility for allocating water and for summoning people to make repairs after each rainy season falls upon a senior male in the relevant clan, an unpaid role termed in Kiswahili "leader of the furrow(s)." Those intending to use water arrange when they will get their turn--normally six hours at a stretch--with the furrow leader. All such arrangements are verbal, but backed by the threat of a communally enforced fine--a goat, or from three to five kgs of sugar and tea for all, or perhaps fifty shillings--levied against anyone taking water out of turn. There are no water charges, and access to water depends very much upon the precise location of a person's plots. Since many farmers have several plots, it is quite common for an individual to belong to two or more furrow groups. Farmers with larger plots get the use of furrow water for longer periods, though in some villages Yoshida reports it was claimed tailenders receive priority (Yoshida, 1985:57).

The Pare furrows are rarely more than 10 km long. They employ the same construction techniques already described above for Kenya. After the heaviest rains in each season have passed, the furrow leader will mobilize its members to repair the temporary intake weir. Such repairs and cleaning of the main furrow were traditionally done by men, it being said that if women did it the water would go backwards rather than flow. In practice, women do sometimes participate, and usually do so in the lowland areas where water is most scarce (Yoshida,1985:58). At this time there is usually a communal cleaning of the entire furrow to prepare for the irrigation season, a task organized by the furrow leader. While the furrow is in use, members are supposed to contribute to its maintenance (sometimes done jointly on a given day of the week). On branch furrows, each plot holder cleans the portion nearest his plot.

As can be expected, there are conflicts between villages where furrows draw water from the same river. The usual custom is for each village to take its turn (zamu) one week at a time. On one furrow with branches, the flow regime has been divided into five sections, with each getting three days in turn. Without having any volumetric measurement, villagers adjust to scarcity by shortening the duration of access but keeping the proportions between users the same. During the dry season, it has been the customary practice that upstream villages nearer the source use the water during the morning and afternoon, leaving night watering to the downstream villages on the plain. In the severe 1984 drought, the lack of any water, even at night, forced the chairmen of the downstream villages to negotiate with the mountain villagers for release of more water (Yoshida, 1985:60-61).

The traditional arrangements for water management just described has been modified further following the Tanzania Government's creation of village government units from the mid-1970s onwards. The village government established for each neighborhood consists of a village council (with a Chairman, Secretary, and Village Manager) and five sectoral committees: 1) security and defense; 2) production; 3) planning and finance; 4) building and transport; and 5) education and welfare. Most villages have taken over responsibility for furrow management if one or more furrows are important to members. Typically, a subcommittee in charge of irrigation affairs has on it one representative for each furrow or section of the village. Yoshida notes (1985:55) those appointed to the irrigation sub-committees were probably already the traditional water managers.

Co-option of Traditional Institutions

As indicated earlier, the contemporary interest in African traditional irrigation has arisen by analogy to the Asian experience. The underlying hope has been that by building upon existing institutions, farmers' participation in and acceptance of irrigation could be increased (FAO, 1985; Mock 1985). To what extent does the detailed evidence reviewed above support this hope?

First, most of the systems encountered in Africa are by civil engineering standards of minuscule size without a major technological input into the water conveyance system. If such systems have strategic importance, as indeed the "swamp rice" and "fadama" systems of West Africa do, it is because of their aggregate impact upon securing the food supply of hundreds of smallholders. It is extraordinarily difficult to deal with a dispersed network of very small plots by means of modern engineering approaches. Even when suitably "small-scale" units are designed, they require machinery, construction and a financial structure quite different from most indigenous African systems. This is abundantly clear from the failure of World Bank attempts to assist "swamp rice" projects in West Africa, and seems equally the case for externally sponsored small projects in Niger, Senegal and Kenya.

Second, Africa's small-scale irrigation is labor intensive. Even where the traditional technologies are widely employed, when farmers have the option of buying modern pumps or obtaining salaried employment, they quickly abandon their indigenous technology. It has been the spread of high volume pumps which has eliminated traditional shaduf and sagia pumping from Sudan and the Sahel. Small systems are as vulnerable as larger ones if farmers discover more rewarding uses of their time.

Third, many small systems have suffered from declining water supplies, either a falling water table during the extended drought of 1983-85 or the removal of forests which protected the catchment areas. Under conditions of drought or of population increase, small systems enjoy no automatic advantages. In East Africa, the proportion of the national population which relies upon small-scale irrigation remains extremely low.

Fourth, traditional water management appears to have been closely interconnected with local religious and political authority (in Sahelian West Africa) or with clan and neighborhood based elders' committees (in East Africa). Rights to use water were acquired by virtue of residence, kinship, and propinquity. It is misleading to term these systems as being "village" or "community" owned. Specialized corporate bodies to supervise, maintain, and expand the system did not exist in their own right, but were rather an outgrowth of the social network. People gained access to water by being or marrying clansmen. To obtain benefit from water required a large labor input, which discouraged many households from making the attempt even when it was technically feasible.

Many African regimes have acted as if traditional authorities constitute a barrier to full national integration. In Tanzania after independence one of the first steps taken was to remove the chiefs and then the local councilors who had been the link between communities and the nation. At a later date, Sudan similarly abolished its local authorities. In Kenya, the influence of clan leaders is often perceived as a threat to national unity; the chiefs and sub-chiefs who represent the government are appointed officials. Across much of the continent increased commercialization is eroding traditional mechanisms for co-operation, while increased bureaucratization of the political system excludes the kinds of leadership which might support indigenous irrigation. Pump-based projects which are spreading rapidly for the commercial growing of spices and vegetables are generally undertaken as the private investments of the local elite.

The prospects for community-managed, surface systems appear most promising where the national regime encourages the formation of village-level committees or village government, as Tanzania has since the mid-1970s. What matters is not whether the institutional form is indigenous or introduced, but rather that the locus of control should remain <u>within</u> the community.

CHAPTER FOUR

TECHNICAL DIFFICULTIES

It is apparent from field visits that many African irrigation projects have experienced technical difficulties associated in one way or another with the physical system for distributing water, with soil conditions, or with the agronomy of field crops.[1] Obviously, a high incidence of technical difficulties will result in shortened project life and lowered productivity, dramaticaly reducing the actual benefits farmers will receive. The persistence of such difficulties within schemes established under donor financing is at the same time puzzling and especially unfortunate. The justification for using scarce external funds on an expensive technology is presumably because by this means countries can buy the extra attention to technical aspects which modern irrigation requires. Yet we find many examples of donor-designed and funded projects operating far below their target capacity. And, of course, because such projects generate insufficient revenue for loan repayment, national leaders may be forced to divert funding from other sectors to cover the shortfall. If left unresolved, technical difficulties can become the cause of additional problems throughout the entire system.

Several of the field engineers interviewed for this study affirmed that Africa's problems are basically not technical in nature. The technology, one is told, can be applied universally. Successful irrigation in places like Israel, Egypt, Morocco, and South Africa indicates that adverse field conditions do not constitute a major obstacle to employment of even quite sophisticated irrigation technologies. The problem lies instead in the larger social and political schemes, where people refuse to provide the kinds of support and utilization which the technology requires. From this standpoint, there is little learning required of specialists, but much improvement needed in the general administrative system before irrigation will become a viable option in many African countries.

This diagnosis of the "problem" in African irrigation is rooted in actual field experience, not to be lightly dismissed. Nonetheless, by externalizing all responsibility for error, it excuses technical specialists from making necessary adjustments in their own modes of analysis and work. Why, for example, do we see the same mistakes being repeated at the design stage in project after project? Why are so many irrigation projects in Africa designed and justified for double-cycle cropping when it is common knowledge that few projects can attain such cropping intensities? Why do field specifications continue to call for

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[1]A useful study which reviews difficulties experienced in 15 Sahelian projects is Brondolo's (1985) Irrigated Agriculture in the Sahel: The Donor Experience, Washington, D.C.: Office of the Sahel and West Africa, Agency for International Development.

wire gabions in surroundings where people have a high incentive to steal the wire? As we will see below, there are numerous lessons of this nature which have yet to be absorbed by the civil engineers who design African irrigation systems.

This is itself significant. By parceling out specialized tasks within the project cycle, donors have insulated the specialists involved at the design phase from the necessity of learning from past mistakes. On larger projects, several firms may be involved and the staff will come from a number of European countries. Those writing specifications and designing scheme layout rarely have the opportunity to see the scheme in actual operation. The lack of feedback is in our view a serious weakness in how African irrigation has been institutionalized to date.

Problems with Remote Sensing

The potential advantages of remote sensing technologies for assessment of water resources are well-known.[1] Water is unique, in that it is near the extremes in its thermal and dielectric properties. In four key wavelength regions subject to remote sensing--reflected solar, thermal infrared, active microwave, and passive microwave--the presence of water (either surface water or soil moisture) can often be inferred with a high degree of reliability. Similarly, growing plants appear conspicuous when examined in the appropriate wavelength band. Thus, the aspects which show most clearly on satellite imagery--surface water (if not turbid), moist soil (if not under broadleaf vegetation), fresh plant growth, surface salinity, and linear geologic features (such as fault lines)--happen all to be of great interest in water resource and irrigation planning.

For Africa, a potent further reason for using remote sensing has been its promise of yielding synoptic coverage of large and often remote areas only very thinly covered by ground stations. It should be recognized that while the North American Desert is approximately 1,300,000 square kilometers, the Great Sahara Desert is over 9,000,000 square kilometers in extent (El-Baz, 1979:384). The fact that each LANDSAT image from the earlier orbiters covers 35,000 square kilometers is thus a suitable area for reconnaissance coverage when one must deal with huge zones like the Sahel and a number of countries where travel is difficult and cooperation sometimes minimal. The initial applications of LANDSAT imagery to water resource planning produced enthusiastic reports. We were told, for example, that by this means the University of Nebraska determined that 9,000 new center pivot irrigation systems had been installed in the state between 1972 and 1976 (Cragwell in Deutsch et al., 1981). Perhaps the LANDSAT images and digital tapes might yield equally

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[1]Among numerous sources on remote sensing, particularly valuable is the 1979 symposium edited by Deutsch, Weisnet and Rango, Satellite Hydrology, Minneapolis: American Water Resources Association, 1981. See also Paulson and Shope (1985).

dramatic findings about African water resources.

There were as a consequence several initial projects aimed at testing remote sensing applications in an African context, e.g., in Botswana (a study of the Okavango Swamp), in Tanzania (water planning in Arusha Region), groundwater exploration in the Sudanic zone of West Africa (Burkina Faso, Benin, and Ghana) and a study of surface drainage in Niger (see papers by Hutton and Dincer, Zall and Russell, and Kruck in Deutsch et al., 1981). More recently there have been many further applications financed by various donors, and the World Bank even found it necessary to issue an atlas of LANDSAT imagery for Africa. A good example of remote sensing applied to countrywide land use planning is furnished by the USAID/TAMS study of Mali completed in 1983 (Projet Inventaire des Ressources Terrestres, Mali [PIRT]).

Despite its popularity among donors, remote sensing imagery turned out to have pronounced limitations when uncritically applied within Africa.[1] First, the initial LANDSAT orbiter only passed overhead once every 18 days. If there was cloud cover, or perhaps nobody had requested coverage, long gaps might occur between useful images. The repetitive imaging needed for monitoring seasonal trends proved impractical, except in limited areas with good coverage. Second, even with further development, the technology could only offer at best a resolution of 80 meters. Peasant farms were simply not large enough to yield distinctive signatures except where in some cases the political administration forced farmers to grow a uniform cash crop in blocks. More typically, each pixel recorded a reflectivity not subject to unambiguous interpretation. Third, without the recti-linear boundaries characteristics of the U.S. landscape, it proved difficult to locate mapped units on the ground. It is obviously much easier to use LANDSAT imagery for planning purposes where mapped units do coincide with actual farm and field boundaries within known administrative units. Fourth, when applied to unfamiliar terrain the imagery requires more, rather than less, ground-truthing. For example, freshly cultivated soil and eroded land often given similar signatures; or again, the provisional hydrogeological mapping mistook cattle trails and bush tracks for geologic fault lines. And fifth, because of the small size of African houseplots, human settlements were usually indistinguishable from the surrounding bushland.

Compensatory techniques were developed, of course (e.g., computerized linear and edge enhancement), but on the balance this "miracle" technology raised more problems than it resolved. A comparison of predictions based on LANDSAT imagery versus air photos when cross-checked by ground surveys found that while LANDSAT imagery yielded interpretations equivalent to those from air photos in subhumid (savanna regions, Nigeria), it was considerably poorer in arid regions like Saudia Arabia (Kucera, 1984). Even in the United States where landscapes appear more suited to the capabilities of the technology, careful ground checking

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[1]Based on experience with groundwater resource planning in Arusha Region, (1973-74). More recent experience is reviewed in Pech et al., (1986), and Henricksen and Durkin (1986).

against LANDSAT-derived interpretation for individual cells gave a variance between conventional and remote sensing classification of 38 percent in one case and about 29 percent in another (Cermak et al. in Deutsch et al., 1981).

These and numerous other technical difficulties have generated widespread disenchantment with remote sensing among natural resource managers. Their scepticism is bound to increase once satellite costs begin to be passed on to users, as is now being proposed. Then too, bad luck has plagued the later stages of LANDSAT development. The big breakthrough was to have been the installation of a "thematic mapper" on LANDSAT-4. The thematic mapper had greatly enhanced capabilities, measuring pixels of 30 m x 30 m in a swatch 185 km wide; yet another development was the multi-spectral resource sampler (MRS) which can read pixels 15 m x 15 m on a 15 km wide swath. The two were to have been jointly installed on a new series of satellites (OERS 1 and 2) originally scheduled for launch in 1985 and 1986. However, shortly after the thematic mapper was placed in orbit it ceased functioning. Now funding cutbacks and "privatization" place the whole program in jeopardy, at just the point where the technology could deliver useful, non-military outputs.

Failure to make further use of remote sensing for irrigation planning would be unfortunate. First, it should be noted that while the technology gives rather low reliability for predicting soil types, its performance in allowing estimates of land suitability for irrigation has been more successful (Kucera, 1984). The distinctive "signatures" of water-related features and the synoptic coverage of wide areas which cannot be easily visited on the ground remain very significant advantages.

Second, a substantial investment in institutional infrastructure has occurred. In addition to the early Remote Sensing Institute at South Dakota State University, other field centers have been established at places like Nairobi and Cairo (the Academy of Scientific Research and Technology, Cairo) and Ouagadougou. In the USA, the U.S. Geological Survey at Reston, Virginia, the Hydraulics and Hydrology Branch of the U.S. Army Corps of Engineers and the Resource Observation Division of NASA in Washington have all been active. In Africa, the ILCA headquarters in Adis Ababa have also become involved in remote sensing applications. These and other initiatives provide an adequate organizational base for a much wider use of remote sensing, even though applications to irrigation planning are still in their infancy.

Third, in large part the initial problems we reviewed arose because of a poor match between the scale at which data was retrieved and analyzed and the users' objectives. For site planning of large projects, higher resolution is now techically feasible. Otherwise, some of the most useful environmental monitoring comes from the various weather satellites rather than from LANDSAT imagery. Tucker et al. (1985) proposes that advanced very-high-resolution radiometer (AVHRR) data from the National Oceanic and Atmospheric Administration's (NOAA) meteorological satellites have "significant potential for assessing and mapping vegetation over relatively modest areas." By this means, they were able to integrate weekly satellite data for a 12-month period during the 1983 drought in the Sahel. Such applications appear to allow for continent-wide surveillance of weather and vegetation trends, information which could be of immense importance when planning the focus of cropping within the continent's irrigation schemes. The technology of remote sensing and image processing is rapidly improving and despite problems with the U.S. program, the success of France's SPOT program and the future entrance of the Japanese guarantees a future for the continued application and improvement of remote sensing technology.

Inadequate Soils Information

Soil properties and conditions heavily influence project location and site design in those areas where water supply permits irrigation development. Information on exisiting soils is required for at least four purposes:

- To estimate how much land falls under different land capability classes, an input necessary for area-based planning;
- To screen out potential irrigation sites where soil conditions will be problematic;
- To assist in determining project layout, based on topography and estimates of agricultural potential; and
- To arrive at cost estimates for surface irrigation (since potential water losses may determine whether or not canal lining is needed).

These four uses of soils information require quite different types of assessment, and different densities in regard to data coverage. A good reconnaissance survey may be sufficient for regional planning at a district level, but inadequate to show whether or not irrigated development is actually feasible. Similarly, to classify soils according to the U.S. Department of Agriculture's (USDA's) taxonomy may require laboratory tests far in excess to what the field engineer finds necessary for determining canal layout. A tenant of faith underlying all soil taxonomies is that the soil will reflect local conditions: parent material, slope and past climate. Accurate determination of soil properties thus requires site specific information, obtained in the past by expensive ground surveys. These days aerial photography has speeded up the process of soil mapping (Cook, 1974), but a fairly intensive degree of "ground truthing" remains essential. It should be noted also that different soil properties are significant when evaluating construction costs from those that determine agronomic capability--the primary difference between the U.S. Bureau of Reclamation's "unified soil taxonomy" and the USDA's agronomically-related classification system.

A frequent problem in Africa has been that the necessary types of soils information are not available on an appropriate scale at the times when projects are being selected and designed.[1] Understandably, much of the initial effort in Africa has been directed toward acquiring a broad reconnaissance picture of regional soil characteristics. Such information, while valid, is of little utility for deciding whether or not to proceed with a given project. Because surveys of the kind required are very expensive (Borden, 1984), they are easiest to finance under project funding. Of course, this assumes ipso facto that the project itself should proceed. If a country is lucky, irrigation planners may have access to an experienced soil scientist willing to undertake a quick site visit before project funding is "locked in." More typically, what happens is that survey results do not become available until the project is already at an advanced stage when relocation or redesign cannot be considered.

As an example of this problem, one can take Kenya's large Bura Project, where uncertainty about the suitability of the soils to be irrigated led to extremely expensive design mistakes and dramatic changes in scheme size. As Gitonga comments under "lessons learned:"

> In view of doubtful soils, the first ILACO study initially proposed a 4,000 ha project. This was, however, expanded to 14,000 ha presumably with economies of scale in mind. However, the soils again forced the project area down to 6,700 ha. At 14,000 ha the economic rate of return was 13 percent. This was ... retained even after the project size was halved (Gitonga, 1985:39)

In 1983 the cost overruns caused by the initially grandiose plans caused the Kenya Government to cut the project back to 3,900 hectares even after the infrastructure for 6,700 hectares was already in place (Gitonga, 1985:15).

Where sites are remote (as in lower Tana) and soils information is urgently needed, one can question whether the fine degree of detail required by some classification systems (such as USDA's) is really appropriate. Dent and Aitken question whether soils surveys have not become a "ritual," employed irrespective of the cost-effectiveness of the methodologies. In a retrospective review of crop performance on Nigeria's 5,000 hecatares Bacita sugar estate, they found that in sections under overhead irrigation all the soil mapping units yielded similarly (no significant difference between them) and at about 80 percent of potential. They conclude:

> Results at Bacita have shown that original assessments were wrong in several respects. It seems that there is little justification for attempting to define degrees of suitability once an area has been identified as broadly suited to the

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[1]In four of Brondolo's 15 Sahel projects inadequate soils data led to subsequent implementation problems (1985:12). Soils too porous for rice production were a problem in several projects.

specified use ... Neither relative nor absolute yield from mapping units can be predicted accurately when management capability is relatively low, as at Bacita and elsewhere in tropical Africa. (Dent and Aitken, 1985:38).

The rejoiner which soil scientists might make is that the environments where irrigation projects tend to be located often display complex soil conditions requiring close investigation. The problem is a real one. On the African land surface, composed of underlying pre-Cambrian rocks, soils favorable to irrigation occur in depressional areas or on the toe-slopes of the catenary succession.[1] On the higher areas sandy soils predominate. If irrigated, water losses will be very high and it becomes uneconomic to employ any form of surface irrigation except perhaps sprinklers (which have still higher investment costs). The clay soils in the depressional areas retain moisture, making expensive canal lining unnecessary, but are highly variable in extent, depending upon local topography. Certain types of clay permit pre-irrigation (e.g., in coastal Somaliland or on Ethiopia's Gash River delta), while others do not. The peaty soils in highland marshes of Eastern Africa (Rwanda, Burundi, Uganda, western Kenya and parts of Tanzania) may look similar to the eye, but are often quite acidic, as are also West Africa's coastal mangrove swamps. Under acidic conditions, plants may suffer from ferric or aluminum toxicity as well as from rapid depletion of soil micronutrients when once put under intensive cultivation. All in all, those with access to relevant soils information insist that soil related problems strongly influence the success of irrigation technologies in Africa.

With regard to soil nutrient status, it has often been noted that soils in the lowland tropics lack organic matter and have been leached of essential elements vital for plant production (with the lack of sufficient soil nitrogen being particularly important). One must go above about 1,800 m (the 6,000-foot level) before humus is accumulated in the soil in the way it would be within temperate lands (Young, 1969). It is no accident that the "agrarian miracles" of Africa occur generally in highland areas, as in Kenya and on the Zimbabwean plateau. Elsewhere, instead, soil fertility limitations may be an even more severe constraint on long-run agricultural development than are moisture deficits (see Chapter Five).

The high iron content in plateau soils encourages the formation of lateritic hardpan on undissected surface remnants of the ancient land surface. Young suggests (1969) this relation may indicate that the "ironstone" pavement which often appears when plateau areas are poorly farmed may be a relict feature, formed as groundwater laterite on a poorly drained, nearly level surface prior to valley down-cutting.

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[2]The concept of a soil's catena was in fact developed by Milne from observations made in Tanzania (Milne, 1947). It refers to a segregation of soil types into a regular sequence governed by the interaction between slope and parent material. Catenary sequences are very common in Africa, being found wherever erosion has indented the ancient plateau surface.

Whatever its origins, the emergence of a 1- to 2-foot thick lateritic horizon underlying cultivated fields is associated with the rapid removal of valuable topsoil--a condition observed by the authors in parts of Mali (the Bandiagara plateau) and Niger in mid-1983, and also widely encountered in East Africa. It constitutes an extremely adverse situation for the application of surface irrigation.

On the other hand, the clay soil areas of Africa probably have a higher potential for irrigation than might be realized from temperate zone experience. The growing of "wet" rice in valley bottoms occurs widely throughout tropical Africa. It seems that when rice is produced in this way it generates its own nutrients (a byproduct of microbiological interactions) so that yields do not decrease over time as they would under normal, dryland farming of arable field crops (Swaminathan, 1984). Given the fertility limitations of African soils, this property of wet-rice cultivation is particularly important.

Another advantage of clayey soils from a managerial perspective is the slow rate at which they absorb water--a trait which becomes a limitation under mechanized cultivation. However, hand cultivators without much understanding of plant water needs can simply flood their fields and leave them without incurring either "overwatering" or unnecessary water losses. Furthermore, the deep vertical cracks which appear in such soils when they are dry (responsible for their categorization as "vertisols") means that they are self-mulching through simple mechanical action. Because of the continent's physical geography, extensive areas with alluvial clays are found in a number of countries. These account in large part for the successes of irrigation in Sudan (the Gezira and Rahad schemes), Mali (the Office du Niger and Riz Mopti) and Kenya (the Mwea Scheme). It would appear that further attention to the management of vertisols in an African context is warranted, and would encompass more than half of all irrigation on the continent.

On top of the inherent complexities of African soils, irrigation developers must also cope with the rival classification systems employed by the various major donors active in Africa. While for construction purposes many donors have employed the "unified system" preferred by the U.S. Bureau of Reclamation (and the Army Corps of Engineers), there are major differences in the taxonomies used for assessing agricultural potential. In Africa, the most widely used system is probably FAO's (FAO, 1968). followed by the French devised system in the Francophone countries, and sometimes the USDA soil taxonomy (Soil Conservation Service, 1975) on USAID projects. However, in Zaire one will encounter the Belgian system, while in Angola and Mozambique there is a Portuguese version (also employed in Brazil).

It is at present difficult to cross-relate soil types between these five systems. At a minimum it would be very useful to be able to identify rough equivalencies between the French, FAO/UNESCO and USDA systems. (For a preliminary effort in this direction, from a TAMS study in Mali, see Table 29.) It should be noted that all the scientific work done during the colonial period employed the classification systems in favor within the former colonial power. Furthermore, there has been a

TABLE 29

COMPARISON OF SOIL CLASSIFICATIONS

B4 TAXONOMIE AMERICAINE DES SOLS ET EQUIVALENTS APPROXIMATIFS DES CLASSIFICATIONS FRANCAISE ET DE LA FAO
U.S. SOIL TAXONOMY AND APPROXIMATE EQUIVALENTS OF THE FAO AND THE FRENCH SOIL CLASSIFICATIONS

TAXONOMIE AMERICAINE DES SOLS / U.S. SOIL TAXONOMY	CLASSIFICATION FRANCAISE DES SOLS / FRENCH SOIL CLASSIFICATION										FAO / UNESCO									
	I SOLS MINERAUX BRUTS	II SOLS PEU EVOLUES	III VERTISOLS	V SOLS CALCIMAGNESIQUES	VI SOLS ISOHUMIQUES	VII SOLS BRUNIFIES	IX SOLS A SESQUIOXYDES DE FER ET DE MANGANESE	X SOLS FERRALLITIQUES	XI SOLS HYDROMORPHES	XII SOLS SODIQUES	YERMOSOLS	HAPLIC YERMOSOLS	ARENOSOLS	LUVIC ARENOSOLS	FERRIC LUVISOLS	LITHOSOLS	DYSTRIC NITOSOLS	EUTRIC NITOSOLS	FLUVISOLS	GLEYSOLS
ALFISOLS																		●		
AQUALFS									●											
USTALFS		●				●	●								●					
ARIDISOLS											●	●								
ARGIDS					●	●														
ORTHIDS		●		●																
ENTISOLS																●				
ORTHENTS	●	●																		
PSAMMENTS	●	●			●								●	●						
AQUENTS	●								●										●	●
INCEPTISOLS																				
TROPEPTS		●	●			●	●													
OCHREPTS		●																		
AQUEPTS		●							●	●										●
MOLLISOLS					●	●														
ULTISOLS																	●			
UDULTS							●	●												
USTULTS							●	●												
VERTISOLS																				
USTERTS			●																	

Sources: Aubert, G. et al. *Classification des sols.* s.l., Commission de pédologie et de cartographie des sols, 1967.

FAO / UNESCO. *Soil Map of the World 1:5 000 000. Volume VI: Africa.* Paris, UNESCO, 1977.

Source: Republique du Mali, 1983 Mali Land and Water Resources. Vol. 2 Technical Report. New York: TAMS/USAID.

major and continuing French effort devoted to the reconnaissance of African resources, not only in the Sahel but also in the humid zones of West and Central Africa. In Anglophone Africa, most researchers based their efforts on a preliminary mapping of African soils by D'Hoore (1964, 1968). The limited practical utility of soil classifications based on detailed morphological description was early recognized, and led to adoption of a more ecological approach to land classification (Moss, 1969).[1] Thus, in neither West nor East Africa has the USDA system (generally required in USAID projects) been widely employed until quite recently. Most local counterparts working on soils mapping and land classification will have been trained in either the FAO or the French system. The overall effect of having several overlapping and noncomparable typologies in use is to minimize the carryover between projects and to limit the accumulation of soils expertise within individual countries.

Limited Prospects for Conjunctive Groundwater Use

There are substantial areas of Africa where because the higher lands receiving rainfall are situated around the periphery, the lay of the land would seem to favor groundwater accumulation within the interior. Geographers recognize five major river basins on the continent: the Djouf Basin crossed by the Niger River; the Chad Basin into which the Chari and Logoni flow; the Sudan Basin crossed by the Nile; the Zaire Basin drained by the Congo River; and the Kalahari Basin from which the Zambezi flows (Figure 4). If, for purposes of illustration, we take the Chad Basin, it is claimed that quaternary sedimentation is about 470 m (2,000 feet) deep and contains sandy zones which are important aquifers (Pullan, 1969). The other major basins also contain sites which are locally favorable for groundwater extraction, as do some of Africa's coastal plains and river deltas (though such water is often saline).

In actuality, however, even in the Sahel and Sudanic zones of West Africa, there are large areas where rocks underlying the catchments are impermeable, the soils have low infiltration capacities and evaporation losses are high. Such areas produce little groundwater recharge, despite topographically favorable conditions (Ledger, 1969). Rodier (1963) points out that there is overall little variation in geological conditions in Africa's vast tropical regions (excluding East Africa's highlands), which are underlain either by the old granite gneissic shelf of pre-Cambrian rocks or a cover of Ordovician sandstones. In the former, "there is no possibility of finding deep underground reserves," while in the latter there is "...very little possibility" (Rodier, 1963:184). In our view, this is a valid statement concerning the limited

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[1]Thomas and Whittington's (1969) work, Environment and Land Use in Africa contains several excellent chapters on land classification in tropical Africa, reflecting the British experience. For the American approach to tropical soils, see Bornemisza and Alvarado (1975). The British versus American approaches to soils classification are dealt with in Butler (1980), Webster (1977); and Buol et al. (1980).

general prospects for conjunctive use of groundwater as a supply for irrigation water in Africa.

Nevertheless, in certain areas groundwater availability does overlap places where small-scale irrigation might be developed. Probably the most important of these occur throughout West Africa's Sahel zone, where human and animal populations exceed the carrying capacity of rainfed agriculture. As de Ridder et al. (1983) point out, most of the Sahel lies just north of the pre-Cambrian substratum which is so prominent in central Africa. The landscape can be considered as a series of large depressions (synclines) that have filled with erosion products over a very long period. Many cycles of deposition and erosion have taken place, explaining the generally flat topography of the Sahel. The last cycle of deposition occurred in tertiary times, and is known as the Continental Terminal. The prospects for groundwater extraction reflect the past history of particular sites.

If we take Mali as our example, according to de Ridder et al. (1982) one finds three major geomorphological units: (1) a sandy complex comprised of deep and relatively uniform eolian sandy soils (characteristics of the northern Sahel); (2) a detritic complex developed on sandstone or laterite with very heterogeneous soils (more typical of the Sudanic and savanna zones to the south); and (3) a fluviatile or lacustrine complex of fossil sediments originally laid down in depressions and flood plains. de Ridder et al. estimate the proportions of land under these three major complexes for Mali and for the Sahel generally as follows (1983:17):

Complex	Mali	Sahel
Sandy	40%	50%
Detritic	30%	30%
Fluvialtile/lacustrine	30%	20%

A 1976 CIEH study estimates that there is a continuous aquifer below about 50 percent of Mali's areas, at depths ranging between 20 to 60 m. Generally, the depth to groundwater increases from south to north; daily yields in the north average about 50 cubic meters going up to 75 cubic meters in the south, but there are wide fluctuations depending upon site location (CIEH figures cited in de Ridder et al., 1981).

Outside this area, the availability of groundwater depends on local characteristics and is extremely variable. In the sandy complex infiltration is high, but because the rainfall is so low and erratic, water occurs only at seepage points and takes the form of a desert oasis. In soils developed on sandstone and laterite, there are large patches of bare hardpan with no infiltration; and both soils and vegetation are very heterogeneous. In places the water collects into stagnant pools, but more commonly is drained by numerous "wadis" (resembling the "arroyo" of the American Southwest).

Soil erosion can be serious, and land degradation is widespread. In the fluviatile or lacustrine sediments, which can be either recently formed or of fossil origin, the deeper layers are clay loam often overlain by eolian sandy loam. This complex lacks natural drainage, so runoff collects into floodplains or temporary ponds. Such floodplains are a feature in Senegal, Mali, Niger, Chad and the Sudan (de Ridder et al., 1983). Thus, the three complexes evidence quite different groundwater characteristics, with high yield supplies suitable for irrigation occurring infrequently.

The best-known instance of extensive development of groundwater for seasonal irrigation comes from the riverine flood plains (or fadama) of northern Nigeria. In Kano State, for example, there are said to be some 160,000 hectares of fadama land, of which some 13,000 hectares were under cultivation in 1981 (Stern, 1981). In Nigeria as a whole, a 1979 agricultural sector review by the World Bank estimted 800,000 hectares of mostly fadama land was under traditional irrigation, up from 120,000 hectares farmed in this way in 1958 (Wright et al., 1982). The technologies in use are very simple, consisting either of shallow wells or boreholes employing either 2-inch steel pipe or 3-inch PVC casing. While traditional lifting devices like the shadouf are still sometimes in use on the hand dug wells, small gasoline powered centrifugal pumps are the most popular for shallow boreholes (Carter, 1984).

Carter describes in some detail the adaptation of Indian technology for low-cost fadama drilling, using three variations of jetted or "washbore" technique, as well as small, trailer-mounted drilling rigs (of a rotary hydraulic type which can sink a hole to 60 m and are commonly used with 4-inch pipe casing). Under local conditions where boreholes are only 20 m deep, jetted washbores using Indian techniques cost a few hundred Naira each, in comparison to about 2,000 Naira each for those drilled by the U.S. rigs (Carter, 1984). On average, about 0.6 hectares of fadama lands are cultivated per family, slightly more than what can be irrigated from one borehole based on the technologies currently in use (Hazell, 1984). Available data suggest a farmer can make a profit of N 1,500 from one off-season crop grown on half a hectare (Hazell, 1984), and the technology continues to be popular. Nevertheless, by international standards these are very small-scale, low-yield supplies.

Along the eastern side of Africa, the groundwater situation is complicated by the Rift Valley system of volcanic mountains and internal drainages. The mountains do sometimes provide aquifers, but water quality is often a problem both on the slopes and in the alkaline basins. Elsewhere one encounters the same pre-Cambrian continental shield, which yields a characteristic topography of peneplain and scattered inselberg hills with granitic outcrops. Of course, where there are alluvial plains below highland areas, such as in Tanzania's Kilombero Valley or the Lower Shire Valley of Malawi, conditions for groundwater extraction are much more favorable but, by the same token, such areas can often utilize surface sources.

Some additional comments are in order with regard to the prospects for groundwater extraction from the "hard rock" pre-Cambrian shield area which covers large parts of Tanzania, Zambia, Malawi, Mozambique and Zimbabwe. The higher elevations where populations are concentrated occur where the underlying bedrock has been uplifted in large blocks, giving the escarpment landforms so typical of the region. From a groundwater perspective:

> The weathering of granite and gneissic rock produces a shallow (generally less than 30 m), extensive and more or less continuous aquifer. Although relatively thin, this aquifer is of great importance as a source of rural domestic water. In contrast, the underlying unweathered bedrock is rarely a significant aquifer. Even where fracturing may produce somewhat higher local permeability, the available storage in the fresh rock is negligible. A borehole drilled into fresh rock will draw on the storage of the overlying weathered zone aquifer. (Chilton, 1983).

The importance of the weathered zones as the main source of groundwater was not adequately realized throughout the region, where it is common to find boreholes drilled to depths of 100 to 150 m in a futile attempt to increase yields. Chilton summarizes the problem as follows (1983:283):

- The borehole and dug well programs have grown up independently. These two large, widely dispersed and costly activities have been implemented separately, without coordination and without due consideration for the most appropriate abstraction method...

- Within the borehole program both siting and construction were carried out with little understanding of the occurrence of groundwater.

- The poorly designed boreholes were themselves a major contribution to the very high cost of hand pump maintenance.

There are many technical difficulties which accompany the reliance on limited recharge borehole supplies for small-scale irrigation. These include:

- Low average yields;

- The high opportunity cost of water, which must also support domestic needs and livestock;

- A tendency for such sources to become depleted at the end of the dry season;

- Dangers of damage to drill-rods when a well may be drawn dry by continued pumping;

- Problems of shut-down when fuel cannot be obtained for the pump; and

- A dependency upon imported parts and equipment, leading to extended periods of down time whenever a breakage occurs.

These problems, which are seen repeatedly, explain why African policy-makers are reluctant to depend on deep well pumping for irrigation, particularly in the hard-rock zone.

If small-scale irrigation is implemented based on deep-well pumping, the existing experience with domestic supplies should be drawn upon. Both the Scandinavians and the Dutch have been especially active as donors for domestic and community water supplies. Their experience with problems of institutionalizing borehole pumping and maintenance is well documented in the literature (see especially Lium and Skofteland, 1983; Falkenmark and Lundquist, 1984).

Falkenmark (1982) gives several examples to illustrate how a failure to consider local contexts in the transfer of water-related technologies often leads to project failure, mainly because of a lack of effective organization at the local level for maintenance. Thus, what appear at first to be "technical difficulties" are in reality a consequence of institutional incapacities; unless the latter are provided for along with the initial intervention, it will soon fail. Four conclusions can be drawn from the village water supply experience which are equally relevant for small-scale irrigation projects (Falkenmark, 1982:94):[1]

1. Low-cost technologies, especially those which are imported, are not necessarily economical or appropriate to serve the rural poor;

2. A certain level of standardization is required in rural water supply systems if efficient management is to be achieved;

3. Research and inventiveness at the local level should be encouraged; and

4. Local industries for the manufacture of handpumps, pipes, simple excavating devices and other equipment involved in rural water supply should be developed with a view to increasing self-reliance.

The main exceptions where groundwater can be cheaply developed for small-scale irrigation are along major rivers where the water table may lie close to the surface or on the toe-slopes of hilly and escarpment topography. Neither situation requires deep well drilling with all the complications just outlined. On riverine plains, the need arises because of the extreme seasonality of the annual flow. In the toe-slope situation, soils are generally fairly deep and groundwater supplies ample

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[1]Other valuable sources are the series of AID-financed "WASH Project" reports, issued by Camp, Dresser and McKee, and several World Bank publications (see O'Mara, 1984; Carruthers and Stoner, 1981; IDRC, 1981; and three publications on water development by ILCA [Edwards et al., 1983; Sandford, 1983; and King, 1983]).

for small-scale purposes. Planners have been slow to recognize that human populations are already concentrated within this zone because of easier access to dry season water for humans and livestock alike.

Failure of Intake Structures

Throughout Africa, as one visits individual irrigation projects, a problem often seen is the failure of "headworks" or intake structures. Sometimes these are filled with sand, and no longer function during dry periods when most needed. Others stand high and dry above a down-scoured river channel. Still others have been stranded when the entire river changes its course. Such failures are usually catastrophic for the linked distribution and farming systems; without a source of water, irrigation ceases as abruptly as it began. Intake structures with their associated pumps and gates are comparatively expensive. Their relocation or repair exceeds local construction capability. Such failures are a dramatic indication that planners were insufficiently aware of local realities. As already noted, the prevalence of these faults in African contexts is evidence of poor feedback between field units and planners. Since these problems are widespread, let us examine briefly some likely causes.

First, on many of Africa's rivers volumetric measurement based on flow gauges and water height indicators are either lacking or recently installed. In other instances statistics exist, but are misleading (because readings may be taken only at intervals, missing the high and low extremes) or unreliable (gauges destroyed during a flood or records falsified). The interesting fact is that despite these known weaknesses in hydrologic data, relatively expensive structures are designed based on existing official data without efforts having been made to check official figures against local farmers' recollections. Spot checking in the field can usually indicate past high water levels. Farmers generally possess definite knowledge of changes in a river's course and of the low levels during dry periods. The failure to employ such readily accessible information indicates, therefore, that a project was designed "from a distance" without attention to the kinds of practical details which will cause it to succeed or fail. The proximate faults in site design are in such instances indicators of an institutional failure at the design stage. After all, similar faults can occur in the American Southwest--but the difference is that the large farmers who will be affected will usually take the initiative to insure that plans are modified before construction is completed.

Second, an intake structure may fail after several seasons because of local changes in its immediate environment.[1] A sedimentation buildup on the main channel may cause a river to overtop the protective dikes. Erosion may occur which is itself an indication that the design was

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[1]See "Improved Headworks for Reduced Sediment Intake" (Kraatz and Stoutjesdijk, 1984); based on Malawi's experience with small gravity-fed systems.

inappropriate. Such problems can usually be solved by a greater exchange of field experience among a country's irrigation engineers. Smaller African rivers may carry high sediment loads during the flood season, requiring modifications in intake design. Rapid undercutting of concrete or masonry structures is also a problem nearly everywhere, and should be anticipated in the initial design. If these problems persist, however, one must assume that the construction agency is failing to learn from its own field experience--an inadequacy which has serious implications concerning the future of irrigation in that setting. Such difficulties may also indicate a lack of involvement by local farmers, who are in a position to have organized remedial action or at a minimum to have warned the parent agency a serious problem was developing.

The third probable cause is the most serious because of what it indicates about longer run land use trends in the project environment. If land use in a catchment intensifies and there is a period of drought, changes in soil surface conditions may lead to vastly increased runoff once a normal pattern of rainfall recommences. A major storm at the beginning of such a cycle, even when it lies well within past limits, may trigger catastrophic flooding in a river system which may have appeared to be relatively stable up to that point. Surface runoff is therefore a variable factor which can show marked changes in response to land degradation associated with failures of plow farming and overgrazing during a time of drought. Changes of such magnitude usually cannot be anticipated in a project design, so that any prolonged period of drought will be followed by numerous structural failures if heavy rains then commence (a likely outcome we should anticipate in parts of northeastern Ethiopia, which feed several of Sudan's major irrigation schemes).

Loss of Storage Dams

Similar difficulties afflict water storage dams, which are often necessary on small catchments because of the intermittent flow of smaller rivers in a hot, tropical environment. Two types of failure should be distinguished (though the first makes the second more likely): (1) rapid siltation of the reservoir; and (2) structural failure of the dam. In project appraisal, a 30- or even 50-year projected life may be used when estimating benefits from construction of a dam. Under tropical conditions where land use cannot be controlled in the catchment above the dam, its actual life may be considerably shorter. In mid-1984 Wells (1984) visited several small dams in Niger and found that in 15 years of operation, sedimentation had reduced reservoir storage capacity by one-half in one case, and one-third in two instances. Where slopes are greater, as in East Africa, the problem is more serious. In one extreme case outside Arusha in northern Tanzania, Murray-Rust found sediment yields of 640 cubic meters per square kilometer, so that a small dam constructed to assist pastoralists in 1960 would have an "economic life" of only 15 years (Murray-Rust, 1973). The reservoir completely filled and then the dam breached in 1974, one year ahead of Murray-Rust's prediction.[1] We should also note that because sedimentation accumulates in the bottom of the reservoir, during the last few years of reservoir life its shallow depth will be insufficient to compensate for evaporation losses, so that its effective utility during the dry season will be reduced to zero.

Structural failure of the dam itself commonly occurs because the spillway cannot accommodate peak flows. In Africa dam designers look for four critical ingredients: clay soils (to form the seal within an earth fill structure); a comparably long and deep reservoir (to minimize evaporation losses); minimal fill required for the dam itself (to conserve on fuel costs in constructing the dam); and finally, a hard rock zone to serve as a wide spillway. All are important, but the size of the spillway is absolutely critical because of unanticipated peak flows which vastly exceed design specifications. (Of course, if African nations could afford U.S. specifications with concrete lined spillways, the number of failures would be lowered, but the cost per structure would be doubled or even tripled.) Assuming peak flows will occur, field engineers in Africa may design a weak point into the dam itself where repairs can be cheaply effected so that the whole structure is not lost. Two villains make such tricks necessary: the "cloudburst" nature of many African rainstorms (with extremely high intensities of rainfall); and the near "pavement" nature of runoff from bare "hardpan" following a long dry season.

In Tanzania's Maasai Project, which operated under a variety of conditions typical of much of the continent as a whole, we encountered a number of further reasons for the failure of individual dams. Construction often cannot be scheduled to occur during times of optimal soil moisture, making it difficult to achieve adequate compaction and unlikely that protective vegetative cover can be established once the structure is complete. Cement is often prohibitively expensive by the time it has been transported to site, and one soon learns to avoid incorporating concrete structures into a design. Africa has its share of burrowing rodents, whose tunnels can lead to failure of the whole dam if they pierce the clay core. Rapid erosion of the spillway almost always occurs. Cattle trails over the dam become deeply notched through surface erosion, and may also lead to its structural failure. Instead of irrigating on the dam's downstream side, African farmers will plough the immediately adjacent upstream area in the expectation their wives will carry water to the growing plants when necessary. This, of course, greatly accentuates sedimentation into the reservoir. And finally, when one dam high on a watershed fails, this may have a cascading effect leading to failure of all other structures further downstream in the same catchment. In the United States, by way of contrast, irrigation engineers tend to take water supply for granted and may feel it is not even part of their science. Nobody with tropical African experience can afford this luxury, because in Africa it is often at the supply where

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[1]This section draws on the senior author's experience in Tanzania's Maasai Project, where numerous small earthfill dams were constructed (and roughly one-third of them subsequently failed).

irrigation systems fail most dramatically.

Drainage Problems

Drainage constitutes a clear-cut problem area on many of Africa's irrigation systems which incorporate canal systems for surface water delivery. Alkaline and sodic soils are common in depressional areas, where clayey soils improve water retention. Full irrigation without lined canals (which is very attractive economically) leads to a rapid rise in groundwater level and salinization of the irrigated area. This danger is well recognized, but nevertheless often occurs because of the short-run attractiveness of lower construction costs (Carruthers, 1985).

On sloping land there is a necessity that field bunds and the canal system be protected from occasional high intensity "cloudburst" storms, which can occur even in semiarid areas. The erosive power of flash floods must be seen to be believed. Furthermore, where the rainy season overlaps the irrigation cycle, a weekend of heavy rain even when not of "cloudburst" intensity may cause waterlogging of field crops and generalized flooding, made more severe by the superimposed water control structures. Anyone designing field structures for African conditions must anticipate that water removal without human intervention is on occasion just as important as timely water delivery.

A further problem at certain sites (highlighted in the background paper by Weber) is the extreme flatness of the terrain being irrigated. Either very long drainage lines are required, or else pumping must be employed to remove excess water and slow down salinization. Because of the flat gradient, water movement is slow and weed growth rapid. If the supply contains silt, it will be quickly deposited--adding a further burden to scheme maintenance.

On many African sites in semiarid areas of the East African Rift Valley, soil salinity, and sometimes also salinity of supply water, can be major constraints. Because these drier areas are also subject to periodic drought and to a high level of environmental stress, there can be heavy political pressure to use available sites even when salinity is present. In the longer run, of course, either saline buildup will occur or a new round of investment will be needed to install tubewells for powered groundwater extraction.

Inoperative Pumps

In Africa today there are probably more pumps that do not pump than there are those that do. At least with dams or gravity-fed intakes, we are dealing with passive structures which, once constructed, may last for some ten to twelve years before being rendered inoperative. Pumps, when employed by unskilled operators without benefit of adequate mechanics and parts, may not last through their second season--the actual experience of many Action Blé-Diré farmers during the first phase of a USAID-assisted Mali Project (Chapter Three). Avoidance of unnecessary pumping is one of the first rules of thumb a neophyte engineer must learn in tropical Africa. This is true in even quite well endowed countries like Kenya, as the following extended case study illustrates:

> The Malka Dakka scheme is capital intensive, investment costs are estimated to be well over Ksh 200,000 per ha (=$16,000): water is supplied by diesel pumps, furrow irrigation is done by syphons, land preparation is mechanized and the scheme is managed by a hierarchically organized, imposed management team from the Ministry of Agriculture, assisted by expatriate technical assistance. Farmers' participation in scheme affairs is minimal. The management is assisted by a staff of mechanics, builders/carpenters, agricultural assistants, drivers, storemen, clerks, watchmen, and whatever. Only junior positions are held by Boran.
>
> Needless to say, recurrent costs are high and, in spite of all external financial aid and high-level management staffing, scheme performance has been and remains very poor. In 1980 responsibilities were transferred to the Provincial Irrigation Unit at Embu and the expatriate team withdrew, leaving further financing to the Kenyan Government. Since then the scheme has operated on a shoestring budget. There has been no money to buy spare parts for machinery, much of which has been cannibalized and lies idle and rusting, and often no money to buy diesel to operate the pumps. At present some 276 people, nearly all scheme farmers, receive food-for-work in the scheme. The major work is the digging of a 4 km long gravity intake canal so as not to depend any longer on the expensive and risky pumps. The pressed and reluctant diggers, most of whom are women and children, still have over 1 km to dig. Many men seek survival for their families by trying to find a job elsewhere. 'At Malka Daklaa an air of despair hangs like a pall over the Scheme.' (Kortenhorst, 1983: 18-19).

Similar outcomes (for similar reasons) are encountered in many of Africa's other small-scale irrigation projects based on pumped water.

The ironic fact is that in theory pump-based water delivery has several major advantages when contrasted with expensive canal delivery systems. Pumps come in many ranges and sizes. They are ideally suited to small perimeters located alongside major rivers such as the Senegal or Niger, where the lift required ranges from about 5 to 15 meters. Small pumps can be removed for repairs, or repositioned between seasons. Their cost is within the reach of the more commercially oriented farmers, particularly if several farmers pool their investment. There is no necessary linkage to a particular crop, so that farmers can grow whatever is most profitable at the moment. Finally, pumps can be linked to various types of delivery system--including overhead sprinklers, a mode of delivery not yet fully exploited in Africa. For all of these reasons, but most especially the ease of matching pumps to small perimeters, almost all of USAID's first generation irrigation projects in the Sahel have relied upon pumping, and will probably continue to do so in the future (Brondolo, 1985).

Even so, irrigation planners must come to terms with the peculiarities of pump operation under typical African conditions. Pumps apear to have been very problematic when introduced into the more remote settings where small schemes are often located. The sources of difficulty are the following:

- The great vulnerability of "orphan" equipment which cannot be supported within the immediate commercial environment;
- The fact that a pump breakdown may immediately threaten the associated production system;
- Poor maintenance, which leads to a high rate of breakdowns and rapid deterioration of equipment;
- Frequent problems associated with obtaining fuel or power to keep pumps operating;
- Farmers' inability to pay operating costs at the times needed;
- Difficulties caused by fluctuating water levels, which may exceed a pump's lift capacity; and
- The generally poor quality of backup services (mechanics, parts, assistance, etc.).

These are the seven main reasons, though one could also cite various failures of design and poor choice of technology as contributory factors reflecting back on inadequate irrigation planning.

There is little in this list which will appear as a surprise to a field engineer; similar "first generation" problems occur widely throughout the tropics. The point to note is perhaps instead the interactive nature of the problematic factors. For example, "orphan" equipment (meaning units without a local supplier's representative) is even harder to support when farmers are penniless and there are no commercial suppliers. At the same time, one can expect that poorly trained and equipped field mechanics will be especially clumsy when dealing with an unfamiliar make and model of pump. Indeed, we would stress that as a general rule the introduction of a few units of some new model or equipment type is bound to fail over the longer run except under unusually advantageous circumstances, e.g., a fully commercial economy like that of central Zimbabwe's, or perhaps in the Kenya highlands. Orphaned units of American equipment introduced under USAID auspices can be found all across Africa--rusting in the yard or being "cannibalized" for parts to keep other units working. With nonconvertible currencies, Africa's field engineers must request every spare part through the central bank, usually months in advance of actual delivery (a delay so long, letters of credit may expire before the item has actually been ordered, and then the whole process must be repeated). Such difficulties affect all types of equipment, of course, but they are especially crippling in pump systems where when a pump is down the whole production process comes to a standstill. Breakdowns tend to occur at the peak periods when a pump may be run at beyond its rated capacity in order to alleviate a high level of moisture stress in the field crops. A failure then puts the whole crop in jeopardy, perhaps leading to farmers' inability to repay pumping costs.

Poor maintenance is cited in most field reviews as a strongly contributing factor behind pump failures. It was a major factor contributing to poor performance in five of Brondolo's 15 cases: Mauritania, Gouraye; Niger, Tara; Senegal, Bakel; Senegal River Polders; and the Gambia Agricultural Development (1985). As in the case of inadequate canal maintenance (discussed later in this chapter), this is actually a symptom of more deeply rooted problems in how the system functions. Interviews with French engineers indicate that often African officials within the Sahel assume well engineered systems do not need maintenance. Similarly, in East Africa the attitude is prevalent that routine maintenance is a "luxury" to be undertaken at those times of the year when funds are in surplus and equipment utilization low. We have probably all experienced the temptation to forego maintenance when funds are short or equipment is in heavy use--a temptation which becomes especially acute in poor African countries. Then, too, the connection between doing routine maintenance and long equipment life is not immediate and obvious; it must be taken as a matter of faith. And finally, maintenance immediately suffers when tools are missing or one cannot obtain the correct types of lubrication fluid (a common problem within Africa's underequipped field workshops).

Before we criticize African field technicians in this regard, we should note exactly the same tendency among donor-sponsored projects. When projects become short of either money or time, one of the first things to be compromised is the effort directed toward institutionalizing adequate maintenance procedures. Perhaps the earliest area to suffer is in regard to training the farmers themselves. Nobody seems to be particularly good at this task; outside of the artificial world of project activities, bottom-level mechanical skills are usually conveyed by example and by apprenticeship, not by formal training. Lacking effective instructional modules, most project managers are uncertain how to actually train farmers in pump operation and maintenance. When projects fall behind schedule, the pressure becomes almost irresistible to begin distributing pumps irrespective of advance preparations (again, the situation seen in Mali's Action Blé-Diré Project). Similarly, cost overruns can mean that the inventory of spare parts is never actually made operational, and this in turn forces mechanics to cannibalize new equipment. All in all, maintenance is a difficult function to institutionalize, and therefore tends to be sacrificed when projects run into logistic and scheduling difficulties.

Problems with fuel supply appear to be more severe in Africa than on any other continent. Most African pumps are powered by diesel engines, except for the very smallest ones. The "problem" arises in several contexts. First, out in the more remote areas of Africa imported fuel is simply not available for extended periods. Second, physical storage is difficult because there are often no storage tanks, and instead all fuel is kept in 44-gallon drums. As Keller et al. (1982) noted in regard to Senegal's Bakel Project, the consequence is often that fuel becomes dirty while being transferred. A third problem is that because of the high prices for diesel fuel out in the "bush," unofficial diversions are commonplace. Drums will be delivered a quarter empty or, even worse, topped up with water to appear full. In turn, using watered fuel will necessitate frequent replacement of injectors.

For engineers, it may be helpful to think of the national fuel supply in a typical African district or province as if it were a limited recharge aquifer. During times of low demand the system is not under much tension and supplies will be locally adequate. However, once the aggregate capacity of the system is exceeded there are bound to be random breakdowns in supply and the peripheral areas will lose out to centrally placed locations. This insight (which comes out of work Keller and others have done on pump systems in Bangladesh) explains the tendency of shortages to occur just when fuel is most needed, and often in places where irrigation is under development. Without fuel, pumping ceases--a situation observed on a visit to Somalia's Lower Shebelle schemes in mid-1984.

A technical difficulty often encountered in Africa is the varying level of the supply from which water is being pumped. Toward the end of the dry season supplies usually shrink dramatically, with perhaps a river going almost dry or a lakeshore receding outwards into white dust. On Africa's smaller sand rivers, the usual practice is to site the pumping station as close as possible to a deep point in the riverbed, but obviously on a wide river like the Niger this will usually not be feasible. In the Sahel countries, principally on the Senegal River, the mounting of pumpsets on movable skids has been tried. While generally regarded as a success, skid and float mounted pumps have their own problems. It is easy to get the coupling from engine to pump out of alignment, the mounting may shake apart from engine vibration, routine maintenance becomes more difficult and list or unsteadiness of floats can adversely affect the lubricating system or load the shafts and bearings unevenly (Keller et al., 1982). However, as Keller's review of the Bakel Project suggests, at many sites there really is no cheap technical alternative within the same cost range. Efforts should be directed at improving the design of existing systems.

The problem of cost recovery within subsistence agriculture is, of course, not unique to pumps. However, irrigation by pumping does require continuous financial outflows from some source. By mid-season the less commercially oriented farmers will have exhausted their cash reserves. Here the use of annual income and yield estimates within apraisal documents hides the fact that many farmers have insufficient weekly cash flow to sustain pumping through into harvest. Unless backed by an effective credit scheme, they may be forced out of irrigated production at mid-season, even after having incurred substantial production costs.

The willingness of farmers to pay their own operating costs can become an issue if pumps are part of an official scheme (as they often are in Africa) and support services are obviously inadequate. One such situation is described by Keller et al. from Bakel:

> The Aroundou perimeter is served by one of the five Marlo pumps ... Just prior to our visit they had their fifth breakdown since obtaining the pump two years ago. This last time the pump shaft broke and was out of commission for three weeks. It was obvious from the appearance of the paddy crop that this last breakdown severely reduced yield. (1982:47).

As in other aspects of irrigation development, it is the general weakness of commercial support services through much of Africa which puts the entire burden for pump support on project staff or on the farmers themselves. In the case of the pumps, this partly explains why so many are inoperable.

Poor Field Leveling

Under traditional modes of African irrigation, the water lifting devices in use had extremely small capacity. Channels were seldom more than a few meters in length, typically feeding into small earth-walled basins only a few meters square. Most farmers also lack a source of power sufficient for leveling large field areas; hoes are used to move small quantities of earth whenever leveling is required. Thus, whether it is because the traditional system did not require level fields or because of severe constraints on the ability to move soil, the consequence has been that fields being irrigated are often sloped and uneven. A further indication of the rudimentary state of farmers' irrigation knowledge is the widespread practice of creating field turnouts with a hoe whenever water is needed, rather than depending upon fixed structures or siphons.

Inadequate Canal Maintenance

Signs of poor maintenance are abudnantly evident on field visits in all parts of Africa. One sees wide cracks in the lining of main canals, leading to cavitation and piping; secondaries and tertiaries are often choked with weeds; broken bunds allow water to flow freely between field units; gates may have been stolen from control structures; and so forth. Such failures occur both at the scheme level (usually under agency control) and at the farm level.

For farmers there are a number of reasons why maintenance is frequently neglected. The possibilities include:

- Absentee plotholders, who are not present when maintenance is required;

- Competition between maintenance tasks and non-irrigated farming, an especially serious problem if the rainfed cycle overlaps the irrigation cycle;

- Unwillingness of women to contribute free labor toward their husbands' speculative involvement in irrigation;

- The "common property" nature of maintenance, which does not become cost-effective unless all farmers do their part;

- Failure to appreciate the returns which can result;

- Insecurity of tenure, which militates against making permanent improvements; and

- A desire to use vegetative growth as fodder for animals.

Obviously, these causes will vary from household to household and project to project. All of them can be important in the African context; and where there are several, overlapping reasons for not doing maintenance, perhaps the most intriguing question is why a few farmers do provide this input.

At the scheme level, the failure to do maintenance is more puzzling. The high costs of employing salaried staff to operate an irrigation scheme are usually incurred in expectation that the staff will see that vital common operations are carried out. Nonetheless, the reasons why maintenance is poor may include:

- Design and construction faults when systems are built;

- A severe constraint upon recurrent expenditure;

- Unrealistic expectations about what farmers will do;

- Lack of suitable equipment; and

- Failure to understand the importance of routine maintenance.

Again, on occasion all can be important. Shoddy workmanship is frequently evidenced during the construction of physical works, so that further attention to maintenance may be imperative right from the start of scheme operation. Often irrigation projects are caught with too many salaried staff and a fixed operating budget, virtually guaranteeing that maintenance activities will be neglected. Staff imbued with the notion that farmers are privileged to receive an irrigation plot may find it easy to insist that all maintenance should be farmers' voluntary contribution. But an even more basic problem is the attitude that maintenance is a "luxury," to be done only when the scheme receives some financial windfall. Comments one hears from scheme staff indicate a general failure to comprehend that routine maintenance is the key to longevity of a system's physical works, as well as to the efficiency of water application. Instead, the larger administrative system rewards those who ignore maintenance requirements, since it is usually easier to obtain external financing for rebuilding a scheme than it is the recurrent funds for keeping it well maintained from the start.[1]

It is not customary to think of maintenance as something which must be managed, but, in fact, that is how it must be conceptualized if it is to be taken seriously. The usual situation one sees in Africa has been described by three ILO experts as follows:

> Development programs generally fund new investments, leaving governments to fund maintenance. But governments rarely find those funds. Besides, maintaining older facilities is never so politically exciting as opening new ones. Thus, most maintenance departments are undermanaged and understaffed. Maintenance manuals, plant drawings, lists of recommended spares and data for lubrication and routine maintenance are rarely adequate. Investments in maintenance workshops, facilities and stores are usually slighted or misdirected.... Managers then face impossible situations--building up the necessary maintenance capabilities whilst trying simultaneously to deal with the immediate needs of neglected facilities. (Donarski, Heath and Wallace, 1983:10)

Although directed toward industrial projects, these remarks apply with equal force to water development activities. Here, too, the heavy involvement of external financing leaves projects without a guaranteed source for covering necessary operational costs (the recurrent cost squeeze already commented upon above). However, there is the further disincentive that in many African countries the operational capacity for water development is vested in different agencies from those supervising irrigation projects. Ian Rule (1984:2) points out that in Zimbabwe it is the resident engineer's staff who does the initial construction of dams and siteworks for irrigation projects. While the construction team has the necessary lifting equipment to install pumps and gates, once they leave there is nobody else with this capability in the local environment (a common reason for the breakage of expensive pumps and engines). In Nigeria, while irrigation comes under the newly formed river basin authorities, the operational capacity exists in various water boards formed at an earlier stage to secure municipal water supplies (Siann, 1981). Thus, the agencies receiving construction funds are not the ones with the responsibility or capacity for doing routine maintenance.

African policy makers need to be made aware of the tremendous savings (particularly in foreign exchange) which a well-implemented maintenance program can realize. While adequate cost data for irrigation projects are not available to us, there is experience in other sectors to draw upon. For example, the World Bank found that the overall economic returns to road maintenance projects averaged 40 percent or more (on eight major schemes financed in 1978), as contrasted to 24 percent on construction of new roads. As the Bank points out:

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[1]A point made by a number of those who discuss the problem of recurrent finance in development schemes. See the Club du Sahel, 1982; Finney, 1984; Gray and Martens, 1982; and Over, 1983.

> The high returns basically reflect the great profitability of small expenditures to maintain the full-service value obtainable from very large earlier investments in construction. But they also suggest that some shift of additional resources into maintenance would be worthwhile in many countries. (World Bank, 1981:5).

The ILO had equally promising results from a pilot program on industrial maintenance within Ethiopia. Several Ethiopian factories realized estimated savings of over $1.2 million in the first year of the program, and the cost/benefit ratio appeared to be at least 8 to 1 (Donarski et al., 1983).

Weed Infestation

It is not sufficiently recognized that irrigation development can, if not carefully managed, intensify and spread weed growth. A good example is Tanzania's Mbarali rice scheme, which while a "success" at an earlier period, is reported to have experienced serious weed infestation in recent years. Weeds tend to out-compete the introduced crops when irrigation water is poorly applied, and they thrive when maintenance is neglected. Outsiders should note that sorghum and rice were domesticated in the same zone of Africa where these are now irrigated crops (Harlan, 1975). Backcrosses with indigenous varieties are an ever present danger.

Weeds also out-compete introduced crops in colonizing soil which has been disturbed during perimeter construction. Firestone describes one such situation observed in Niger in March of 1984:

> In spite of being a well-designed perimeter, Konni I was a disaster as far as cultural practices are concerned... The areas between the primary and tertiary canals were covered with weeds in seed. The seeds were blowing into the irrigation water and being carried to the growing fields. This compounded an already serious weed problem. The prolific sedgenut grass (Cyperus rotundus) is widespread throughout the cultivated fields of the perimeter. The farm ditches are full of weeds... The farm drains are in similar condition. (Zalla et al., 1984: C-7).

In both the Sahel and East Africa, red rice constitutes a major crop pest. It was observed in Tanzania's Ruvu scheme by Weaver et al. on a 1983 visit. Once established, the seed becomes incorporated into the harvest of the sown rice and spreads thereby to other areas of the country. (One suspects that the Ruvu scheme may have been the source of Mbarali's problems, since both are managed under the same parastatal agency.) Seed inspection is poor in many African countries. It is quite common for government farms to supply farmers and other schemes directly without any effective means of seed certification. The local staff working on individual schemes may have insufficient technical background to pay attention to this vital aspect. Thus, as irrigation spreads, so do the weeds associated with the major irrigated crops.

Further evidence in support of this observation comes from the "swamp rice" farming of coastal West Africa, where often it is the infestation by weeds which forces farmers to abandon diked areas after several seasons. After a certain point, the labor required to control weed growth exceeds the energy value of the crop and the homestead will begin production at a new site.

Aquatic weeds have also become a serious problem over much of central Africa. In the 1950s the water hyacinth was introduced into parts of Zaire from the Americas. It spread rapidly into neighboring Uganda and Sudan, reaching as far southward as the Kariba reservoir in only a few years. In environments like those of the Nile Basin, its growth has been phenomenal. The plant blocks irrigation pump inlets, clogs canals, completely covers smaller irrigation channels, makes fishing difficult and provides suitable breeding sites for mosquitoes and good shelter in its roots for Bulinus snails, the vector for schistosomiasis. It has been responsible for a large increase in the costs of river transport, necessitating constant effort to keep channels clear. According to a Khartoum workshop held in 1975, water losses brought about by its presence could run as high as 7 billion cubic meters per year, equivalent to one-tenth the normal yield of the Nile, or 1.78 times the amount of water which the first phase of the Jonglei Canal was to yield (1975:2). The same source estimates that between 1959 when control efforts began and 1975, Sudan spent 6,829 milion Sudanese pounds (almost 20 million in U.S. dollars) trying to keep the water hyacinth in check. The worrying fact is that the Nile Basin waters (vital to Sudan, Uganda, Ethiopia and Egypt) seem "extremely vulnerable" to infestation by a number of other alien plants as well (1975:6).

It must be admitted that the Sudanese (with help from the U.S. Academy of Sciences) have shown imagination in proposing countermeasures (1975:6). Among the possibilities listed are:

- Continuation of the current spraying program;
- Introduction of insects, such as Florida's water hyacinth beetle;
- Fermentation of water hyacinth to produce methane;
- Use as animal feed (difficult but technically possible);
- Conversion into compost, rich in plant nutrients;
- Introduction of herbivorous fish, such as the grass carp;
- As a food base for introduction of water buffalo;
- Introduction of other acquatic weeds (e.g., bladderworts) which scavange the miracidie and cercariae of bilharzia;
- Drying and grinding of the leaves to form a non-toxic human food (with 25 to 29 percent crude protein);

- Introduction of spikerushes ("underwater lawns") which out-compete even the water hyacinth plants; and

- Use in sewage treatment to produce a source of fertilizer ingredients.

Failure of Double-Cycle Cropping

The addition of a second irrigation cycle in each year (termed here "double-cycle cropping") is an apparently attractive way to gain higher utilization of expensive irrigation facilities. In Asian wet rice cultivation, for example, externally financed irrigation schemes have often had as their objective instituting a second cycle of cropping within the assisted perimeters. (Where double-cycle cropping is practiced, one needs to incorporate estimates of cropping intensity--e.g., 175 percent to reflect a situation where three-fourths of the fields are also used in the second cycle.) This tactic greatly boosts the cash flow within the farming system, and with it both profits and apparent repayment capabilities--at least in theory. In practice, within Africa various donor-sponsored attempts to institute double-cycle cropping have usually failed over the longer run, and do not lead to markedly higher farm-level profits. A relevant example is furnished by small-perimeter rice schemes in The Gambia where, under The Gambia Agricultural Development Project (began in 1973), the aim had been to realize double-cropped rice on some 1,200 ha of riverflats. Impact evaluations done in 1982-83 found actual cropping intensities of between 20 and 40 percent, a steady decline from a 95 percent level in 1981. The Mwea Scheme in Kenya has also instituted double-cycle cropping of rice in recent years. However, despite the huge increase in effort this move entailed for scheme management, actual on-farm returns were boosted on average only about 30 percent (Kenya National Irrigation Board, Annual Report for 1983).

The technical difficulties asociated with irrigated double-cycle cropping under African conditions include the following;

- Because of certain climatic constraints within each year, the attainment of double-cycle cropping may require an overlap between the harvest of one crop and land preparation for the next crop. This creates an automatic "labor bottleneck" for the household labor force, as well as intense pressure on project resources.

- Sometimes, changed climatic circumstances may require different varieties for the second cycle.

- "Backward linkages" in the form of aggregate supply needs (for fertilizers, input delivery, etc.) will become greatly intensified. Input capacity is already a constraining factor at present low levels of utilization.

- Service organizations need continuous access to inputs, fuel, storage, etc. under a double-cycle cropping regime. At the present time farmers' cooperatives in much of Africa use the dry season for transport and restocking, so that inputs are only held in bulk for a limited period. For the field units, organization for the coming season usually takes place during the slack period after the harvest is moved out.

- Instituting a second irrigated cycle leaves the farmer with no time in the year for food crops or other, non-irrigated enterprises. The competition for farmers' resources between rainfed and irrigated farming then becomes direct and unavoidable.

- Often, African males are accustomed to different dry season pursuits (e.g., livestock trading or short-term labor migration). The returns from such alternative occupations have been sufficient to threaten participation in the second cycle's activities by the men.

- The extended moisture regime and growing period provides a more favorable environment for the buildup of pests and spread of human and plant diseases. Successful second cycle cropping implies that disease and pest control measures are already available and effective.

- The drawdown of existing soil nutrients, amount of soil compaction and buildup of root nematodes or similar parasites are, of course, accelerated. Similarly, if deep drains have not been installed, second cycle cropping may accelerate soil salinization.

In short, the problems of second cycle cropping are mostly caused by the overlapping of activities and the intensification of demands put on the larger economic system. In systems where labor is already in short supply at peak periods and where the performance of the economic system is weak, double-cycle cropping makes sense when farmers have reached an advanced stage of commercialization (e.g., market gardening around a capital city). It is also feasible in those economies of northern and southern Africa where input and support services are already prepared for year-round operation.

The Livestock Issue

Irrigation schemes and livestock projects co-exist within the semiarid parts of Africa. Both represent preferred (or "privileged") technologies, often promoted in the past as the scientific answer to the needs of local producers. Their co-existence should not be surprising. If one considers the areas where irrigation is most used outside of sub-Saharan Africa or the wet rice zone of Asia, the mutuality between these two forms of production is clear. The countries where irrigation is important are often places either where the traditional economy was based on livestock raising, or where a modern, livestock industry has been established: e.g., in Egypt, the Mid East, North Africa, Australia, and the American West. Usually, irrigation has been accompanied by commercial production of forage or feed used for livestock. While obviously not all irrigation is for this purpose, it does seem that most commercial livestock producers who have the option do employ irrigation in one form or another.

The reasons for doing so are clear enough. The lack of forage is often the key constraint limiting a producer's overall productivity during the long dry season characteristic of such areas. Even a small amount of irrigated forage, if supplied to the foundation herd or used at critical periods, can make a significant difference. Livestock can also utilize crop residues, and off-season "ratoon" grazing. For poorer farmers, livestock can provide a liquidity much needed for managing farm and household finances (not a minor contribution in areas which lack adequate rural banking services), in addition to milk, meat, manure and animal power. We have seen that shortages of on-farm energy severely limit peasant farmers' ability to do field preparation, just as cash shortages leave them unable to pay irrigation costs in a timely manner. The integration of livestock enterprises alongside and within irrigated field crop production is thus normal and economically advantageous development. And, in point of fact, some livestock occur almost everywhere within Africa's irrigation schemes, even on projects where the keeping of livestock is technically illegal. As one visits individual schemes, almost always one encounters herds of cattle, goats, sheep, and even camels coming or going to the fields.

Somewhat surprisingly, then, livestock production is often not mentioned in official project plans when irrigation is being established. Here the main exception is the Sudan, where farmers' insistence on growing fodder crops alongside the "official" cotton has long been a point of contention. Elsewhere, if livestock are mentioned at all it is usually to stress the problems stock-keeping causes to management. Scheme staff find that the grazing of livestock along dikes (such as on the "partial" water control structures at Riz-Mopti in Mali) accelerates erosion, while their movement from field to field within flood-basin schemes destroys the bunds. Where dry season irrigation is practiced, farmers must protect their growing crops from livestock once the off-scheme grazing is exhausted. Sometimes tenant farmers encounter angry pastoralists, whose traditional dry season grazing along riverine terraces is usually disrupted by the physical layout of irrigation works. For these reasons, both water engineers and scheme managers would often prefer to keep livestock entirely outside the irrigation perimeters.

Let us for a moment try to view this situation as it will appear to local livestock producers. It is insufficiently realized that virtually all irrigation development in Africa has occurred on prime areas for livestock production. In any system for extensive livestock raising, those areas which are near to water and which have soils that retain moisture are likely to be crucial to the carrying capacity of a much larger zone. The producers' ability to tap seasonal grazing in very dry lands which may receive only 1-2 months' rainfall in each year depends heavily upon access to dry season grazing capable of supporting much higher stocking densities. Typically, such areas are found along rivers with richer alluvial soils, and in the clayey depressions where grass remains green into the dry season. For the same reason, deltaic areas with richer soils were also heavily used by livestock producers.

The Senegal delta formerly used by pastoralists is the site of the irrigated Richard Toll plantations, just as is Mali's inland delta on the Niger River for the Office du Niger and Riz-Mopti projects. The Tana delta is targeted for imminent irrigation development by the Kenya Government; it, too, while officially "unused" is a key resource for the Pokomo and Orma pastoralists on the lower Tana. Sudan's major irrigation schemes, with a few exceptions, occur alongside major rivers on lands previously used by pastoralists. Most of Ethiopia's irrigation development in the Awash valley occurs on 'Afar grazing lands in the Danakil depression. Irrigation development on Somalia's lower Shebelli has removed a long strip of alluvial and deltaic lands from pastoral use. The large-scale development of pumped irrigation near Lake Chad in Nigeria has similarly affected transhumant Fulani herds. For pastoralists, particular problems are caused by the linear layout of most irrigated perimeters: Sudan's Khashm el Girba scheme, for example, runs for some 60 km along the Atbara River. In addition, on a number of projects the water diverted into irrigation (a consumptive use) would have flowed otherwise into drier areas in even greater need than those served by the irrigation. This objection can be raised against several of Northern Nigeria's projects, the World Bank financed SEMRY projects (affecting the main source of water for Lake Chad), Mali's Office du Niger, and possible future projects in Ethiopia curtailing water flowing into Sudan and Somalia.

It is usually claimed in project documentation that the lands to be developed for irrigation were not being productively utilized. In the Acres/ILACO survey for Kenya's Bura Scheme, for example, the value of pre-project production was estimated at about four Kenya shillings per hectare (Gitonga, 1985:8). On other schemes it has sometimes been claimed the riverine lands were "unused." The most charitable explanation is that where livestock herds move seasonally into distant grazing, experts and national policy-makers have tended to see the area as being unoccupied. This distortion is frequently enshrined in the legal code, which in many African countries gives little protection to customary use in instances when such rights conflict with modern development or national plans. But it seems that the need to portray irrigation as being economically advantageous is also partly at fault. Realistic assessment of the value of "traditional" production on riverine lands would greatly alter the benefit-cost weighting. Even when the value of production foregone is eliminated, and claiming yields more than double those usually attained, African schemes cannot be expected to show rates-of-return above about 5 percent (Rangeley, 1985:14). More realistic recognition of the value of production foregone would make it impossible to justify irrigation investments in most instances where large schemes are anticipated--a point we return to in Chapter Eight.

Perhaps irrigation planners have been naive about the value of livestock production within the drier countries where irrigation tends to be a privileged technology. A steer in good condition was selling in northern Nigeria for nearly a thousand dollars (U.S.) if valued at the official exchange rate in May of 1986 (as reported during a field visit to Kaduna). In 1979, when Nigeria was embarking upon its major irrigation schemes in the North, FAO estimates put the national herd at about 12 million cattle, in addition to some 33 million smallstock (data cited in Jahnke, 1982:230). These animals are largely kept in the sub-humid and semiarid zones to avoid tsetse infested pastures--the parts of Nigeria where irrigation development was the Government's major development focus in the late 1970s. Much the same situation was found in the Sudan, which at this time was estimated to have over 17 million cattle and almost 30 million smallstock. As with northern Nigeria, so also central Sudan has a rapidly growing urban sector furnishing a major internal market for livestock products. Outsiders sometimes fail to realize that a once sleepy town like Kano is today a city of perhaps 3.5 million people, which explains why even smallstock have become quite valuable in recent years.

More generally for the Sahel zone and its extension into the African horn, livestock are in several countries the nation's most important single export. The situation varies from year to year and from country to country, but certainly for Somalia as for Mali (both countries where irrigation developments have received priority attention), the livestock sector has long been the mainstay of the national economy. While the numbers of animals kept do not rival countries like Ethiopia, Sudan, or Nigeria (with Tanzania being Africa's four largest livestock producers), the proportionate importance of livestock is much greater. Ignoring for the moment camels and smallstock, if we count just cattle, the FAO estimates for 1979, put the national herds in Mali at around four and a half million, in Somalia and Chad at roughly four million, in Senegal, Niger and Burkina Faso nearly three million, and in Mauritania about one and a half million (cited in Jahnke, 1982:230). The Sahel zone as a whole was thought to contain about 22 million cattle, with another 55 million in the three main countries of Nigeria, Sudan, and Ethiopia. Obviously, these are very gross estimates which even if valid have been strongly influenced by the droughts of 1983-84.

Indeed, one of us visited the Gezira Scheme in December of 1984 when the drought was becoming severe. One was told at the time that virtually the entire pastoral population of animals and people which customarily used lands to the East of the Nile had now moved to be along the main highway running adjacent to the Scheme. Fodder from the irrigated on-scheme fields was just as critical for the survival of the livestock as was the food grown for the survival of the human population. The centrality of Gezira in provisioning a much wider area of the Sudan was obvious, even if the Sudan Gezira Board was reluctant to admit this fact, given the desire to encourage cotton production instead. Thus, the integration between livestock producers and the irrigation sector is much further advanced in Sudan than official policy has in the past recognized, a fact brought out by a mid-1986 survey of livestock in the Gezira area (Blench, 1987). We see this as a desirable trend, indicating it is time for irrigation planners to see livestock as an opportunity rather than as a "problem" in scheme evolution.

Energy Issues

While it is customary to speak of "the energy issue" in relation to irrigation development, as if this constituted a unitary topic, closer examination reveals a range of policy concerns from the national to the household level which may have little in common but all of which are significant in Africa. Here, energy is an issue for various reasons:

- Many countries lack their own fossil fuel sources, but have not adapted their power grid to suit rural consumers (such as irrigation schemes);

- The planning and support for energy matters is usually vested in different ministeries and agencies from those that deal with irrigation;

- Irrigation schemes are usually planned by outsiders who have only a limited awareness of local energy problems;

- Irrigated production is a potential source of renewable energy for countries which lack fossil fuel (following the Brazilian example);

- Shortages of energy at the scheme level--either because fuel is temporarily unavailable or because of power outages--are common;

- The choice of technologies, and in particular, the reliance upon pumping for water lifting and conveyance, has major energy implications and can render projects vulnerable to disruption;

- Within households, farmers lack cheap, readily available fuel. Any larger settlement will eventually exhaust surrounding supplies of wood, leading to impoverishment and hardship unless alternative sources have been provided;

- The labor intensive nature of many irrigated crops (rice, cotton) makes it likely that production targets exceed the energy input which a typical family can manage at peak seasons of labor demand;

- Farmers who adopt animal power require additional forage and shade; there are questions concerning the relative efficiencies of growing irrigated trees and shrubs versus having these inputs purchased by farmers;

- Irrigated production of trees may be essential for environmental reasons, to protect other crops from the Harmattan winds and to minimize wind erosion; and

- There remains also the possibility that in the future solar or wind power could substitute for present sources of energy.

Obviously, these diverse considerations take us far beyond the sphere usually dealt with under the topic of "irrigation development." It is not feasible at this point to review the huge, recent literature on the energy implications of agricultural production (see Smil and Knowland, 1980, Auer, 19). Instead, the aim will be merely to highlight the major issues which future research on African irrigation should address.

The significance of energy policy at the national level for African irrigation arises both because the sub-Saharan countries other than Nigeria and Angola mostly lack fossil fuel reserves, and because until recently many countries had no real energy policies of their own. Large hydroelectric dams were being built at the same time as rural towns in the hinterland imported large diesel generators to provide their electricity. Many countries lacked a national power grid. When long distance transmission lines were built at great cost, there was no means for rural users to tap this supposedly "cheap" power. The fact is that in Africa electric power has been aimed entirely at the industrial sector or at larger urban centers within the modern commercial economy. This has effectively forestalled the spread of demand-led farm and village electrification, and with it any reliance upon hydropower for developing modern irrigation. The situation is especially poignant in countries like Kenya, Tanzania, Zaire, Zambia and Nigeria where long distance power lines pass directly over promising irrigation sites which must instead rely upon unreliable fuel imports. In Nigeria, it is said that when the South Chad irrigation scheme was built, the 33 MW powerhouse with its 9 generators and huge fuel depot required to run the pumps was three times larger than the power station in the state capital at Maiduguri (Andrae and Beckman, 1985:99). Africa's very substantial hydropower reserves are thus paradoxically of little use in meeting the agricultural sector's energy needs.

At the scheme or perimeter level, energy issues can be summarized as being concerned with gravity, diesel, and trees. As already noted, field engineers accustomed to Africa much prefer gravity-fed surface irrigation to the more flexible and modern pumped systems for water conveyance and application. Obviously, when pumps fail the whole perimeter may be put at risk, whereas breakdowns in a gravity-fed system can usually be repaired by local initiative. In terms of cost, a gravity-fed design puts the cost "up front" where it can be financed as a package by a donor, while a pump system is initially cheaper but entails user access to foreign exchange (for fuel and part imports) throughout the life of the system. External design consultants have tended to overlook this point, and must bear at least part of the blame for the poor performance seen on many of Africa's pump-based schemes. Obviously, too, countries which lack hard currency will have special problems in keeping pump-based irrigation systems in operation.

Trees come next to livestock in being viewed as "problems" by many scheme managers. First, there is the technical issue that trees consume water in fairly large amounts, which they transpire into the atmosphere. Second, trees with shallow roots tend to disrupt the bunds and dikes built by the management, and larger trees are a major obstacle to field layout if they are already in place. One of the first steps in scheme construction as often practised is, therefore, to cut down all trees, large or small, within the confines of the proposed perimeter and also along its main supply canal. Third, trees provide refuge for pests, rodents, insects, and birds--all of which become complicating and potentially dangerous factors within a production environment already characterized as having high levels of uncertainty. And, finally, trees tend to become boundary markers valued by their owners, and thereby circumscribing the management's freedom when relocating roads or canals.

None of these apparent disadvantages need be especially serious. In parts of India, Southeast Asia, and Mediterranean Europe, trees have been a usual part of irrigated agriculture for centuries. In the American West, they were planted within farmers' land along canals and roads from the very start. There are well developed systems for irrigated forestry in the arid and semiarid lands of the Near East (see Armitage, 1985). Thus, the claim sometimes advanced by expatriate managers in Africa that trees obstruct irrigation should be viewed as a convenient rationalization intended to protect their power. When we weigh the huge importance of trees to households which are short of fuel, building materials, privacy, and energy-rich root crops, it is simply not defensible to insist that they be excluded from the irrigated system. In parts of Sudan and the West African Sahel, trees are so important as a protection for crops that they may become the primary focus for irrigated production.

A lack of household energy sources remains a signficant constraint within African irrigation development (Haswell, 1985, Pimental and Pimental, 1979). Estimates of the amount of fuel wood a typical African family requires per year vary, but most authors put the per person consumption at between 0.7 - 1.125 cubic meters (Vainio-Mattila, 1987:58). If one includes the wood used for fencing, housebuilding, and other purposes (as well as that removed by production of charcoal for external sale), it soon becomes apparent why shortages of firewood emerge quite quickly around any larger African settlement (Anderson and Fishwick, 1985). Here irrigation schemes are no exception, since few have permitted the growing of tree crops which might have replenished the diminishing off-scheme supply. Vainio-Mattila notes that when the first tenants arrived at Kenya's Bura scheme in 1981, firewood was a virtually free good since the scheme was surrounded by "bush." By 1984, however, the price for a donkey cart load had risen to 50 shs., which doubled to 100 shs. by June of 1986 (Vainio-Mattila, 1987:80).

The loss of trees around irrigation settlements becomes a hardship when families must organize their own trips sometimes of several days' duration to collect firewood from distant sources (Hanger and Moris, 1973). What is ironic about such shortage is, of course, that they need not occur. Deeply rooting species of trees can be planted along scheme roads and tracks--as they are within irrigation systems in Europe and America--and houseplots can be left large enough to accommodate private woodlots. There are marked advantages in the drier zone to having fuelwood plantations as well as windbreaks to protect the field crops.

Despite these advantages, only a few sources analyze the role of forestry and agro-forestry within Africa's energy-starved irrigation schemes: mainly the two case studies by Vainio-Mattila (1987) and Hughes (1984) of the Bura West situation, and a number of other accounts about fuelwood plantations within Sudan's Gezira Scheme. The Bura West example is instructive: despite fuelwood shortages having been anticipated within the project documents and agreed upon by all concerned in establishing the scheme, and despite the presence of a donor willing to support the planting of fuelwood, the agreed plans were not implemented. The scheme management saw this aspect as a forestry department responsibility, leaving the Finnish donor's team to concentrate upon the introduction of fuel-efficient stoves as at least one means to make the diminishing supply last longer.

Health Impacts

The negative health impacts associated with irrigation development in hot tropical climates are well known, but nonetheless constitute an influence of growing significance in many African irrigation schemes.[1] The linkage may be direct, through contamination and water conveyance of diseases like cholera; or it may be indirect, by providing a more favorable environment for parasite vectors (e.g., in schistosomiasis, malaria, sleeping sickness, and river blindness). The underlying situation is that the long dry season acts as the principal factor limiting the build-up of vector populations. The introduction of an irrigation system typically removes this constraint, especially when multiple cycle cropping is attempted in each year, while at the same time creating a style of life and work where people are bound to become infected.

To illustrate this point, it can be noted that on a large scheme such as Sudan's Gezira, it has been estimated that 80 percent of children and up to 60 percent of adults have schistosomiasis. It is said the disease causes an annual loss in labor time equivalent to 30 million Sudanese pounds, and direct costs for human treatment of nearly half a million pounds annually plus another million for molluscicuding the scheme environs (Amin, 1977). (At Gezira, 116,000 cases of malaria are reported annually, and these are thought to represent only one-third of the total (El Agraz, et al., 1986:103). These negative impacts are sufficient to have caused some observers to rate Gezira as a failure (Pollard, 1981), despite the scheme's economic achievements.

The problems posed to people by the spread of malaria and

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[1]See Hughes and Hunter (1970), Kamark (1976), Mc Junkin (1975), Mather (1984), Owen (1973), Stanley and Alpers (1977) and especially Feachem et al. (1977). Sources looking at specific diseases spread by irrigation include Jewsbury (1984) and Family Health Care (1979), while the latter source and Cairncross et al. (1980) are especially useful on techniques for estimating likely health impacts of water "improvements."

schistosomiasis (and potentially river blindness) are fully recognized by most irrigation planners, though not yet dealt with effectively. The large specialized literature on these aspects--which we review below--probably underestimates the true dimensions of the problem, which is of an interactive and dynamic nature. This is not welcome news for proponents of African irrigation, but the issue of negative health impacts needs to be faced honestly and seriously if progress is to occur in finding more effective solutions. Cause for additional concern arises because resistant strains of vectors and pathogens have surfaced quickly in African environments because of the incomplete application of control and treatment measures (creating ideal conditions for the emergence of resistant strains). Other negative influences not considered in the past include the impoverishment of diets through removal of protein sources (typically obtained from inland fisheries adversely affected by the spread of irrigation), the loss of trees and browse (affecting animal nutrition), the increased eutrification of water because of fertilizer residues, the incorrect employment of herbicides leading to higher human mortality, and the build-up of toxic chemicals in the food chain. These problems are potentially very serious indeed.

This rather unpalatable conclusion is stressed at the onset of our review here, because typically health impacts are treated as a residual category within project documentation. The specialized nature of public health concerns renders them vulnerable to professional marginalization within project cycle activities. Once external consultants have contributed their chapter to the project appraisal and a provision has been made within the project design for spraying and disease monitoring, there is little further consideration of the health issue despite its acknowledged importance to the people who must live within an irrigation scheme. To the contrary, the evidence reviewed below suggests that often the negative health impacts absorbed by local residents outweigh the supposed benefits policy makers' desire from an irrigation project. Since the technologies for protecting health and sanitation are well known, what is required are more effective approaches to making them an operational part of scheme design and management.

Potential Health Hazards

To assess more precisely the potential health hazards which irrigation development in the Tropics entails, it is useful to note the four mechanisms by which water-related diseases are spread, and the associated preventative strategies (Cairncross et al., 1980:77-87). The main transmission mechanisms include diseases that are: 1) water born; 2) water-washed; 3) water-based; or, 4) carried by insect vectors linked to water availability (Table 30). Essentially, the strong link between irrigation and increased incidence of water-related diseases occurs because an irrigation system, with its sluices, canals, furrows, and night storage reservoirs provides good if not ideal conditions for the three main modes of transmission, though it can also reduce certain diseases (if it makes it easier for people to wash themselves).

Water-borne diseases are those like cholera or typhoid (both of which have become resurgent within parts of Africa in recent years) where the pathogen is actually conveyed by water itself. Many other serious tropical diseases, such as infectious hepatitis and bacillary dysentery, are also water-carried. For such diseases, improvements in surface water conveyance will automatically increase the potential for infection unless the population using a scheme employs high standards of personal hygiene and enjoys good sanitation. However, there is a positive side to increased water availability. Some tropical diseases (including apparently many diarrhoeal ones) are reduced when people keep clean by adequate washing--hence the category, "water-washed diseases." Ready access to water reduces the incidence of skin and eye infections as well as infestation of ectoparisites like body lice. The third category, water-based diseases, applies to parasitic worms which must spend part of their life cycle in an intermediate aquatic host, e.g., schistosomiasis

TABLE 30

DISEASE TRANSMISSION MECHANISMS AND POSSIBLE CONTROL MEASURES

Mode of Transmission	Preventative Measures
1. Water-borne	Improve water quality Prevent casual use of other sources
2. Water-washed	Improve water quantity Improve water accessibility Improve hygiene
3. Water-based	Decrease the need for water contact Control snail populations Improve quality
4. Water-related insect vectors	Improve surface water management Destroy breeding sites of insects Decrease need to visit breeding sites Remove need for water storage in the home or improve storage vessels

Source: Cairncross, et al. (1980) Evaluation for Village Water Supply Planning, p. 78.

and Guinea worms (*Dracunculus medinensis*). The fourth and final category consists of diseases spread by an insect vector itself, such as malaria, yellow fever, dengue fever, onchocerciasis (river blindness) and trypanosomiasis (human and animal forms of sleep sickness).

Cairncross et al. (1980:81-82) list no less than 36 tropical diseases which are linked by one or more of these mechanisms to water.

Many--like yellow fever, river blindness, cholera, and typhoid--are very serious. There are entire sections of northern Ghana and neighboring Burkina Faso which were abandoned by their original inhabitants because of the incidence of river blindness carried by the Simulium blackfly which breeds in fast flowing water (Walsh, 1985). Thus, the three diseases most often mentioned in connection with African irrigation development--schistosomiasis, river blindness, and malaria--are only the leading candidates among a wide array of potentially serious diseases which can spread rapidly by means of water-linked transmission. Most depend either upon a fecal oral connection (facilitated by water) or upon the presence of insects and mollusks which live in or near water.

Greater awareness of disease risks has led to increasing use of field surveys to determine the probable health impacts of increased water availability in the local environment. The preliminary African results are not encouraging. For example, an examination of 2,524 individuals from 31 Senegalese village found that a broad range of human parasites were already present, albeit at low incidences of infestation (Miller, 1982). In such situations, the creation of a more favorable moisture regime could lead to a rapid build-up of parasites. In Nigeria, Adekolu-John (1980, 1983) warns that the major dams being built are often located in the savanna/guinea zone, where malaria, schistosomiasis, trypanosomiasis, and onchocerciasis are also endemic. Kloos, Lemma and Desole (1978) show that endemic foci of S. mansoni occur in widely separated and remote areas of Ethiopia. The spatial distribution of its intermediate hosts (the snails Biomphalaria pfeifferi and B. sudanica) suggests that development of irrigation may break down the temperature barrier keeping populations segregated, leading in turn to the colonization of new areas such as the lower Awash Valley. Other studies from Kenya convey the same warning, for malaria as well as schistosomiasis; here see Choudhry (1975), Chandler et al. (1976), and Oomen, (1981). The fact is that almost everywhere either the major water-linked diseases are already endemic, or else suitable hosts for the spread of such diseases are established. Where people must work in irrigated fields and do not enjoy safe sanitation, and where furrows and ponds provide numerous breeding sites for insects and mollusks, the three negative forms of water-linked disease transmission can be expected to come into play almost immediately when a surface irrigation system is established. The recent FAO review of African agriculture in the next 25 years cites examples of pre- and post-project schistosomiasis incidences (drawn from the work of Rosenfield and Bower) which corroborate this observation (Table 31).

The focus on schistosomiasis--commonly termed Bilharzia--in the irrigation literature (reviewed by Brown and Wright, 1985) is understandable because of the close association between this disease and surface irrigation in tropical Africa. However, populations continuously exposed to schistosomiasis (which come in two forms, intestinal and urinary, with the former having the more serious medical consequences) can build-up a degree of tolerance. Without denigrating schistosomiasis, which can seriously disable and kill people--especially when they first come into contact with it as adults or where endemicity is very high--we suggest irrigation planners in Africa need to devote at least equivalent attention to the other water-linked diseases, such as malaria, cholera and typhoid as well as hepatitis and various forms of dysentery and diarrhea.

TABLE 31

CHANGES IN SCHISTOSOMIASIS INCIDENCE FOLLOWING

IMPLEMENTATION OF WATER PROJECTS

Country	Project (Yr. completed)	Pre-project prevalence (percent)	Post Project prevalence (percent)
Egypt	Aswan Dam (first) (1900)	6	60% (3 years later)
Sudan	Gezira Scheme (1925)	0	30-60% (15 years later)
Tanzania	Arusha Chini (irrigation)	low	53-86% (30 years later)
Zambia and Zimbabwe	Lake Kariba (1958)	0	16% adults 69% children (10 years later)
Ghana	Volta Lake (1966)	low	90% (2 years later)
Nigeria	Lake Kainji (1969)	low	31% (1 year later) 45% (2 years later)

Source: FAO (1986) *African Agriculture: the Next 25 Years*, Annex II, *The Land Resource Base*, p. 69 based on work by Rosenfield and Bower (1978).

Even less commonly considered are the other health risks which may emerge once irrigation schemes have been in operation for extended periods. For example, in 1981 it was found at Gezira that the mean values for DDT in cow's milk on the scheme were 0.23 ppm, and water from surface wells and canals were found to contain 0.2 and 0.16-1.2 micrograms/litre respectively. Concentrations of DDT in Gezira cows' milk as high as 1.3 ppm have been recorded, in contrast to the WHO/FAO standards of a maximum of 0.05 ppm. Maximum acceptable levels in the U.S.A. are as low as 0.001 micrograms per litre, depending upon varying state standards (El Agraa et al., 1985:129). Modern high intensity agriculture is characterized by vastly increased uses of toxic chemicals, some of which are bound to enter the food chain or to come into contact with human populations in a variety of ways. Pollution risks are further increased where villages have not been provided with safe water supplies or where the drains from one area become the supply for another.

Control Measures

Control over unwanted, negative health impacts is technically possible, but at the price of careful planning and fairly expensive treatment measures. For example, intermittent sprinkler irrigation where water is conveyed in pipes carries much less disease risk than continuous surface irrigation based on open furrows and canals. Similarly, where houses have piped water and safe waste disposal, the spread of water-linked diseases within a population can be much more easily controlled. Basically, a reduction of health risks depends upon breaking the fecal-oral connection required by many pathogens, and upon minimizing the provision of favorable environments for disease vectors and parasite hosts.

To remain effective, control measures must be continuously applied. Stopgap remedial measures based on chemotherapy for diseased humans and insecticides to control vectors can be expected to have a relatively short effectiveness, for the reasons already given and because the poorer African nations are now acutely short of hard currency to finance imports. Haphazardous and partial application of chemical controls actually increases the problem by stimulating the early emergence of resistant strains. This suggests that more attention should be given to understanding the behavioral aspects of disease transmission, the engineering measures which facilitate control, and the very layout and periodicity of irrigation--two important components which have usually been overlooked. It is little use treating water in villages if a scheme has created vast, treeless plains where the only place field workers can defecate in privacy is on the banks of the irrigation canals where people wash their clothes and water their cattle (Charnock 1982).

On the positive side, enough is known about tropical disease transmission to pinpoint the particular sources of danger found on a typical irrigation scheme. These include the standing reservoirs and night storage ponds, reliance upon unlined canals which become colonized by weeds, sluices which oxygenate fast-flowing water, the implementation of extended or continuous irrigation cycles, unsanitary latrines, poorly designed and built drains prone to hold standing water, and shallow wells which draw polluted groundwater or which permit ready surface contamination. Several investigators have reviewed the use of engineering control measures to make irrigation safer, including McJunkin (1970), Ackers and Gowing (1983) and Bolton (1987). Hydraulics Research at Wallingford in England have an on-going research program in Zimbabwe on this topic.[1] A word of warning is that engineers _must_ also consider

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[1]Reported in a special issue of the _ODU Bulletin_ (July 1987, no. 7) on "Health Aspects of Irrigation," _Hydraulics Research_, Wallingford.

the behavioral aspects, since people locally often do not behave in ways which distant experts assume. An especially important innovation being tried out in Zimbabwe's Sabi Valley schemes is a screened and vented pit latrine said to prevent the breeding of flies and vermin. A great deal has been learned about tropical sanitation by domestic water supply experts, and this experience should be tapped within African irrigation planning.

On the negative side, it can be noted that false economies taken at the appraisal stage to lower capital costs frequently entail greater health costs for scheme households. Such "economies" include measures like reduced drainage, the institution of double-cycle cropping (which greatly extends the moisture regime favorable to vectors), crowding farmers onto very small houseplots, standardized field layouts that leave no room for privacy or sanitation, and the adoption of standardized western water control structures which encourage parasite infestation.

The dangers which accompany the incomplete or partial application of control measures are only now becoming recognized in Africa. A resurgence of malaria is a cause for particular concern in a number of East African countries. Packard (1986) notes that while much research has focused on problems of pesticide resistant vector strains, the resurgence of malaria in Swaziland cannot be so explained. Instead, this development appears to derive from a combination of factors: the creation of ideal breeding sites through irrigation; the ineffective application of malaria control measures within Swaziland's sugar estates; an influx of foreign workers known to be potential carriers; and a demographic shift leading to a build-up of non-immune populations living in close proximity to both malaria vectors and carriers. These same factors occur widely throughout much of tropical Africa. Conditions in Swaziland are far more favorable than in parts of coastal East Africa (such as Kenya's Bura West scheme), where virulent strains of chloroquine-resistant malaria are now being encountered. This situation requires close monitoring in the planning of future irrigation schemes.

Perhaps the most basic lessons about control measures are that they must be implemented on a system-wide basis, must be kept in continuous operation, and cannot be chosen piecemeal from the narrow perspective of any single discipline. Tropical ecologies are extraordinarily complex, and measures which may appear sensible from one perspective may yet carry unanticipated negative impacts from another. For example, the fish introduced to control weed growth in canals may also serve as intermediate hosts for human parasites. The trees which provide privacy and fuel also shelter birds, some of which eat insects but others of which consume farmers' grain. Workers brought in from a distance help farmers harvest their crop, but may bring diseases with them and may subsequently spread endemic scheme diseases to other, non-irrigation communities. All in all, it seems that the adoption of irrigated agriculture in the hot tropics assumes that people enjoy fairly high standards of hygiene and sanitation. When implemented where these conditions are not met, the negative health impacts associated with irrigation over time can become the single strongest reason why such technologies should not be adopted.

Further Research

The above review of technical difficulties highlights a range of problems which straddle several disciplines. Conventional approaches to irrigation development segregate the design and implementation activities into separate stages, and parcel out specific tasks to different disciplines. Civil engineers design water control structures and scheme layout; economists do the project appraisal; soil scientists evaluate land potential; agronomists determine plant water needs and the cropping schedule; lawyers may advise on acquisition of land and water rights; public health experts recommend disease control measures; and sociologists do the social impact analysis. This insures at a minimum that eventually an agreed project plan materializes, but it inhibits organizational learning and destroys feedback between different specialities.

Chapter Three documents the low performance which is being achieved on many of Africa's formal irrigation schemes, established in the usual way as just outlined. If African governments, donors, and irrigation authorities wish to improve upon this disappointing record, they must first learn how to analyze and rectify problems which transcend the usual disciplinary boundaries.

We, therefore, bring this chapter to a close by listing the priority topics which this review suggests merit urgent, transdisciplinary attention. The main agenda of topics for future research in African irrigation development would include:

1. Cost containment: Why high costs on small schemes? What factors contribute to the high costs often encountered in African irrigation? What traits distinguish high from low cost schemes? How well are costs monitored?

2. Swamp rice/valley bottom development. Comparative returns versus "full" irrigation. Description of range of present types. Agronomic problems of working with "swamp" rice. Population absorption potential. Types of technology, indigenous and introduced. Suitable frameworks (organization, economic) for intervention. Why poor record to date?

3. Long-run, life-of-project irrigation performance. Document longitudinal performance of irrigation schemes, try to identify reasons why it has been difficult to keep initial levels. Analyze those schemes (like Mwea) which have maintained high yields. Role of social and economic factors, commercialization. Multiplier benefits over project life.

4. Choice of crops. Why such a narrow range of crops being irrigated? Linkages of crop to associated irrigation technology. Biological versus economic efficiency. Import content of various crops. Long run prospects for irrigation of staple and food crops? Linkage to commercialization? Prospects for new crops, either traditional or

oriented to Gulf States? Food versus export crops? Energy, FE, labor, capital requirements?

5. New technologies for small systems. Review of alternative technologies, traditional or modern, suitable for small-scale irrigation. Possibilities to be reviewed include photovoltaics, hand and animal powered pumps, "bubble" irrigation, technical options for supplemental application in low-cost, small-holding or horticultural systems.

6. Vertisol management. Strategic significance of vertisols relative to African agriculture; types of vertisols and potential under irrigation. Energy requirements. Crop responses, agronomic aspects. Construction implications. Indigenous and traditional technologies for vertisol use.

7. Intra-season, intra-year work budgeting. Investigation of temporal aspects of energy demand associated with various irrigation technologies. Temporal profile of available farm power, either under two adult hand cultivation or combined with animal power. Relationship of energy inputs to food requirements, identification of bottlenecks and deficit periods. Energy-disease linkages.

8. Cost recovery mechanisms in irrigation. Why cost recovery has been so poor? Organizational and managerial load implications of alternatives, water charge versus control of marketing chain. Timing of repayment demand versus seasonal cash availability. Alternatives to controlled marketing for cost recovery.

9. Weeds. Document association of weed establishment with irrigation. Degree of weed challenge under varying crops and irrigation technologies. Problems of seed quality, role of irrigation in spreading weed seeds. Labor implications of weed growth, also for maintenance. Economic aspects of weed control in constrained economic systems.

10. Pump-system deterioration. Comparative vulnerability of various delivery systems. Upstream or systemic requirements of pump systems. Cost over life-of-project versus investment costs. Gaps in pump types. Problems of "orphan" technology vis-a-vis pumps.

11. Water harvesting and irrigation. Types of water harvesting in use in Africa. Comparative costs to irrigation. What complementarities? Choice of crops under water harvesting. Role in water management. Indigenous techniques for water harvesting.

12. Energy issues in irrigation. Explore adaptations to the national power grid to facilitate irrigation. When and where to use pumping? Household fuel and power requirements, with and without animals. Design of field systems to incorporate forage crops and trees.

13. Behavioral and engineering aspects of disease control. Identify disease risks associated with various standard designs. Behavioral

assumptions made in site layout from standpoint of disease impacts. Measures to improve personal and household hygiene and sanitation. Implications for recruitment of laborers. Long-term and interactional effects.

14. Maintenance effectiveness. Which features maintained and which failed at present? Maintenance assumptions embodied in project designs and their realism. Relative costs of maintenance versus eventual reconstruction. Differential willingness to do maintenance. Farmers' ability to absorb maintenance costs.

CHAPTER FIVE

AGRONOMY AND IRRIGATION IN AFRICA[1]

Introduction

This interpretative review of the agronomic issues on irrigation in Africa examines the literature of Francophone and Anglophone West Africa, Central Africa, and to a more limted extent, the southern tier of African nations. The literature review is combined with observations from the author's experience in ten African countries.

The chapter is organized in five sections. The first section gives some general considerations on water and agriculture in Africa. The second section provides an outline of the diverse irrigation and drainage methods used. The third, fourth and fifth sections discuss the agronomic issues of rice, sugarcane and cotton production in the region.

The selection of these themes is partly an attempt to examine important agronomic assumptions or assertions made in economic and policy studies of irrigation in Africa, partly an initial effort to place the development of agronomic technology for irrigated agriculture in a broader context than individual scheme or country efforts, and partly a function of available documentation.

Water and Agriculture in Africa - General Considerations

Water, either in amount or interannual variability of rainfall and surface flows, has been generally held to be the major natural limiting factor to primary productivity and crop production in Africa. This rationale has been used to make the case for investment in irrigation as a way of improving the security of food production in the Sahel and other dry areas or of sustainably boosting yields and introducing new crops and double-cropping in more humid environments. However, recent work carried out by Dutch researchers indicates that for important areas of the Sahel, the major limiting factor to primary productivity is soil fertility, not water (de Ridder et al., 1983). Supplemental irrigation doubled primary productivity. Nitrogen and phosphate additions increased nearly fourfold the primary productivity of native rangelands. This work was done in pastoral areas, but it has important implications for study of the issue of relative returns from investment in rainfed or irrigated agriculture in the Sahel. However, even though the nitrogen and phosphate fertilization strategies advocated would raise mean yields, the problem of large year-to-year variations in production and the potential for large-scale crop failure due to drought would remain. In the more humid

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areas greater water control has been sought to increase yields and the reliability of production of sugarcane and rice and, occasionally, perennial tree crops and vegetables (Barnes, 1984; Grist, 1975; Goffinet, 1964; Drachousoff, 1959).

Across both wet and dry environments greater water control has had two primary objectives:

1. To increase yields to a designed or potential level; and

2. To reduce interannual yield variation to a designed level.

In dry environments irrigation has also had the objective to permit the introduction of crops which could not otherwise be grown.

General expectations from irrigation projects are that yields will increase substantially up to a designed level. Economic cost and benefit studies assume that no downward dips in yields and production will occur. However, there are a series of factors that intervene to make actual yield and production fluctuate much more widely than project designers plan. Among the more important ones are:

- Climatic conditions which are more variable or severe than available short-term records would indicate, especially in regards to rainfall, surface flows, temperature and wind velocity;

- Soil variability across a project site that has minor importance for structural work but major importance for operations, water demand and crop adaptability;

- Increasing weed infestation;

- Complex shifts in the insect pest, disease and virus complex as greater water control provides more uniform stands of vegetation and good conditions for pest multiplication;

- Creation of attractive feeding sites for vertebrate pests;

- Unexpected or ignored problems of salinity and compaction that increase with age of the project; and

- Exacerbation of some of the above by poor main system management, operations and maintenance.

This listing of agronomic problems confronting irrigated agriculture leads one to ask about the comparison of this experience with rainfed agriculture. Mean yields are lower and interannual variation greater in rainfed agriculture. But in economic terms, rainfed techniques may provide the greatest net addition to national income, even for a crop such as rice, which produces high yields only with high water availability (Pearson et al., 1981). Arguments can and should be made that greater effort should be devoted to rainfed agriculture. At the same time, there are areas in Africa where improved water control has resulted in fairly impressive production increases. Also, many of the irrigation projects should probably be considered pilot or exploratory exercises. There have been attempts to introduce a new and complex technology into different environments. A reasonable conclusion might be that future emphasis in the irrigation sector should be on improvements to the performance and stability of production from existing schemes and those in the financing pipeline.

Irrigation Methods and Agronomic Production Alternatives

Debate about what is and is not irrigation in Africa has gone on for some time. Most observers include systems based on water application structures or drainage works as irrigation. Several recent authors have pointed out the need, particularly for Africa, to maintain a broad definition of irrigation. This is because a wide variety of local water control adaptations border on what is commonly called irrigation; and fully developed irrigation is relatively scarce in Africa, where water development is costly and often poorly done.

Des Bouvrie and Rydzewski's definition is one to be noted:

> Irrigation can be broadly defined as the artificial control of soil moisture for agricultural purposes with the aim of increasing crop production (Des Bouvrie and Rydzewski 1975:162).

Still other authors (Moris, Thom and Norman, 1984) favor a definition of irrigation which includes systems with only little control of either water application or drainage.

Screening of sub-Saharan production systems with a broad definition of irrigation yields a long list of irrigation and drainage methods. Nine classes based upon source of water, means of water control, drainage provisions and chief crops have been identified as follows.

Class I. Groundwater Use with Drainage and Minor Extraction

Means of Water Control	Drainage Provisions	Crops
Drainage only or with supplemental extraction and watering	Natural, mounding, ditching and mounding	Groundwater rice, sugarcane, taro, sweet potato, vegetables

Locations: Coastal floodplains, fresh water lenses behind coastal dunes, river floodplains, seasonal streambeds, marshlands, inland valleys with impeded drainage. Type sites: Casamance, Senegal "grey soil" groundwater rice zone; North Togo, Kabye mound cultivation of rice, yams and cowpeas in bottomlands (bas fonds); coastal freshwater swamps behind sand dunes producing sweet potatoes in the Cap Vert region, Senegal; riverine swamp cultivation of sweet potatoes, cocoyam, vegetables along Zaire

River. Areal extent small. High value due to proximity to markets.

Class II. Groundwater Use with Intensive Extraction

Means of Water Control	Drainage Provisions	Crops
Hand, shaduf, some pumpset extraction; flooded basin and microbasin application	Naturally permeable	Multistory, oases, dates, vegetables, barley, grain, legumes, henna, fruit trees, forage

Type sites: Oases in areas just south of the Sahara or in mountainous pre-Saharan or enclave areas, e.g., Atar, Chinguetii and Sana, Mauritania and similar sites in Mali, Niger and Chad. Once closely tied to pastoral movements, now generally linked with more permanent settled smallstock. Also, generally in decline and subject to increasing environmental degradation. Dallou system in mountain oases of Niger using oxen to lift water from 4 to 5 meter deep wells. Of great importance locally, but making only minor contributions to national economies.

Means of Water Control	Drainage Provisions	Crops
Large diameter, shallow wells with calabash, watering can or pump extraction. Furrow, microbasin, some advanced applications such as drip	Natural, occasional surface drains	Vegetables, wheat

Type sites: Diverse site from extremely arid to humid, often combined with recessional and swampland cultivation. Walk-in wells in the "Niayas" vegetable production zone of coastal freshwater lenses in Senegal. The Dogon and Lake Zone Calabash system in Mali. Pumpsets in shallow wells around many towns in Sahelian and Sudanian zones. Extraction from stream recharged aquifers in Botswana. Limited in areas extent, high value of product to local economy and to surrounding town areas, but threatened by urban expansion and potable water needs in many areas.

Means of Water Control	Drainage Provisions	Crops
Small diameter boreholes at depth, advanced pumping technology, combined with furrow, sprinkler and drip application	Variable	Wheat, vegetables

Type sites: Burkina Faso pilot wheat project, Sud-Senegal pre-pilot drip irrigation vegetable project, Nigeria center pivot. High costs need high value crops and/or large surface areas in order to be financially viable.

Class III. Rainwater Harvesting

Means of Water Control	Drainage Provisions	Crops
Runoff concentration structures and microbasins, runoff retention dams and flooded basins, runoff retention dams and canals. Supplemental and full irrigation	Varies, usually natural drainage except in larger schemes	Wheat, cotton, sorghum, tree crops, onions, vegetables, maize

Type sites: Concentrated in arid and semiarid zones. Interlinked small dams and flooded areas using recession techniques in central Mauritania. Dallols and Goulbis systems in Niger, Western Sudan runoff around Darfur; small impoundments in Botswana.

Means of Water Control	Drainage Provisions	Crops
Microharvesting structures	Natural	Sorghum, millet, seed melons

Type site: Mauritania in Brakna and Gorgol regions.

Class IV. Capture of Seasonal Surface flows

Means of Water Control	Drainage Provisions	Crops
Spate irrigation canals in interior seasonal river deltas in desert environments.	Natural and enhanced drainage lines	Sorghum, cotton, forage

Type site: Tokar and Gash river deltas in Sudan. Basically an improved recessional system.

Means of Water Control	Drainage Provisions	Crops
Dike impoundment	Natural	Sorghum, millet, pulses, forages

Type sites: Gorgol and Brakna regions in Mauritania which are part of an interlinked system of oases, oueds and rainfed pasture and crop production. Also used in braided stream environment on tributaries and drainage lines to White Nile in Sudan.

Means of Water Control	Drainage Provisions	Crops
Weir diversion of seasonal streams	Natural and improved	Maize, sunflower, sorghum, cowpeas, melons, vegetables

Type sites: Tanzania, Chagga and Meru systems, some of which are engineered with canals. Botswana canal and piped systems from weirs used as supplemented irrigation for rainfed crops or, if longer flows are available, for vegetables and fruit trees.

Traditional flood recession along rivers and lakes	Some surface drains may be cut in wet years	Rice, wheat, sorghum, cowpeas, millet, melons, maize, vegetables

Type sites: Niger and Senegal River floodplains, Niger Lacustrine zone, Lake Chad, small-scale depressions in Mauritania.

Traditional flood retention structures	As above	As above

Type sites: As above. Plus, Malapos in the Okavango drainage area in Botswana.

Dikes, gates and occasionally pumps recession gates	Common main canal and drain, flood at margins	Rice, wheat, sorghum and cowpeas

Type sites: Mopti, Segou and Inland Delta of Mali. Long-term plans to provide pumps along rivers to provide full control and convert to year-round cultivation when dams and reservoirs constructed. Transitional to Class V.

Class V. Supply from Perennial Flows, Run-of-the-River

Means of Water Control	Drainage Provisions	Crops
Pumping from pumpsets or stations, canal conveyance	With or without flood protection depending on site	Varied rice

Type sites: OMVS small, medium and large perimeters. Kaedi, Boghé, Richard Toll, Rosso Area, Bakel in Mauritania and Senegal.

Pumping stations, pipeline conveyance, furrow, sprinkler and drip	Field drains	Vegetables, flowers, fruit trees

Type site: Lac de Guiers offtake at Sebikotane, Senegal. High value, but competition with urban water needs led to greatly reduced operations.

Diversion weirs, canals	Field and main drains	Cotton, rice, peanuts, vegetables

Type site: Office du Niger, Mali.

Class VI. Dam and Reservoir River Regulation

Means of Water Control	Drainage Provisions	Crops
Fresh and salt water inlets to polders	Gravity and pumped drainage, flood control	Rice

Type sites: Sierra Leone, Liberia and the Casamance, southern Senegal.

Class VII. Riverine Grasslands

Means of Water Control	Drainage Provisions	Crops
Flooded, low control, some poldering	Natural	Rice

Type site: Sierra Leone.

Class VIII. Inland Valleys and Swamps

Means of Water Control	Drainage Provisions	Crops
Small dikes and gates	Gravity drainage	Rice

Class X. Surface Flow Exclusion

Means of Water Control	Drainage Provisions	Crops
Isolated polders, with rudimentary inlet and outlet control	Overflow drains	Sorghum, pulses, rice

Type sites: Overland flow zone Jonglei province, Sudan. Lufira Valley, Zaire.

These nine classes give some idea of the scope of irrigation systems that exist in sub-Saharan Africa. They show the dominance of low water control techniques adapted to low intensity crop production. Most of the irrigation techniques are tightly linked to rainfed production in that they are parts of farming systems that occupy primarily freely drained upland fields with a smaller lowland component. Only in arid zones is dependency on irrigated crop production dominant, but in these cases households are supported by a diverse set of economic activities including livestock and crop production in wetter zones, trading or off-farm employment.

Rice Agronomy in Africa

Classification of Rice Production Systems

Among the major food crops of the world, the rice plant is adapted to the widest range of hydrologic and soil conditions. Its adaptive range and the human capacity to push cultivated crops into ordinarily unfavorable areas through modification of the landscape, soils and water availability has led to the evolution of a highly complex set of production systems. The efforts of many to classify these rice systems have generally been based on the type and degree of water supply and control. Two major divisions are usually recognized--irrigated with full water control and rainfed.

To a certain extent, the use of full water control as a criterion to distinguish irrigated from rainfed rice systems is not a useful one. Some areas which are irrigated for one growing season in Asia are subject to natural, regular flooding and use for a second season deep water rice crop under essentially uncontrolled water supply (Moorman and Van Bremen, 1978). In floating rice areas of Mali, the construction of dikes and gates has permitted successful floating rice production in nine years out of ten (Vallée and Truong, 1978; Martin, 1976). These systems do not permit water application before river flooding occurs and would be excluded from the irrigated category on this basis. However, production from these schemes has been more reliable than that from many run-of-the-river pumping schemes on the Niger and Senegal rivers which have been engineered to provide full water control, but in practice have failed to deliver the water with the same degree of regularity because of a series of institutional constraints. In parts of Asia, IRRI (1982) recognizes a category of rainfed distribution and cultivation in humid areas where rainfall distribution and bunding and leveling occur to the point that water control is close to full. These areas use varieties and production techniques developed in full control settings. Irrigation does not always guarantee full water control for rice (Moris et al., 1984). Rainfed cultivation does not always mean the lack of water control.

As evidenced by the classification of rice system hydrologies used by IRRI (1982), it may be more useful for rice research and development to be based on hydrologic regimes that occur during a given growing period than it is to develop varieties and growing practices for irrigation as opposed to rainfed conditions.

For agronomic purposes the IRRI classification is most useful when combined with a knowledge of site factors of topography, soil conditions, major production practices and water control structures. Despite IRRI's best efforts, a great deal of terminological confusion exists about rice production systems around the world. Africa is no exception. Table 32 attempts to correlate the different classification systems most commonly used in Africa.

Hydrology is the main distinguishing characteristic used in these classification systems. No one of them provides an approach that can be

TABLE 32

CORRELATION OF RICE PRODUCTION CLASSIFICATION SYSTEMS

ITTA (Buddenhagen 1978)	MOORMAN & VAN BREEMAN (1978)	FRENCH/IRAT (Seguy et al., 1976)	WARDA (Lewis, 1983)	IRRI (1982)
Irrigated	Irrigated	Irrique	Fresh water, Full Control	Irrigated
Upland A. Dryland	Pluvial	Pluviale Riz de montagne Riz pluviale, draine	Upland Strictly Upland	Rainfed Rainfed Dryland
B. Hydropmorphic	Phreatic/Fluxial	Riz de bas-fond Riz phreatique Riz de nappe	Groundwater Cultivation	Rainfed Shallow Drought and Submergence Prone
Inland Swamp	Fluxial/Phreatic	Riziculture d'inondation	Lowland Cultivation	Rainfed Sahllow-Deep
A. Non-toxic	Fluxial/Phreatic	Riziculture d'inondation	Freshwater Cultivation	Rainfed Shallow, Submergence Prone
B. Toxic	Fluxial/Phreatic	Riz de marais	Freshwater Cultivation	Rainfed Medium-Deep, Waterlogged
Flooded	Fluxial	Riziculture d'inondation/flottante	Freshwater Cultivation	Rainfed Shallow-Floating
A. Riverine	Fluxial	Riziculture d'inondation	Freshwater Cultivation	Rainfed Shallow
B. Riverine Deep	Fluxial	Riziculture d'inondation/flottante	Freshwater Cultivatiron	Rainfed Deepwater
C. Boliland	Fluxial/Phreatic	Riziculture d'inondation	Freshwater Cultivation	Rainfed Shallow-Medium Deep
D. Mangrove	Fluxial	Riziculture d'inondation	Mangrove 1. With tidal control 2. W/out tidal control	Rainfed Medium-Deep, Tidal Swamp
		Riziculture flottante		Floating Rice
		Riziculture de décrue		

applied worldwide without modification. The IITA and WARDA systems reflect West African soil and water concerns. Moorman and Van Breemen's system is based on natural hydrological cycles with many further subdivisions not shown in Table 32. Their subdivisions are based on physiographic types, man-made alterations of hydrology such as bunding and leveling, and flooding regimes. The French classification uses terms based on water supply and depth of standing water. The IRRI system is strongly weighted toward the Asian experience in which most "rainfed" landscapes have undergone so much transformation through bunding, leveling, puddling, flood control, etc. that there are substantial problems in making direct parallels to the rice growing areas in Africa or Latin America.

As indicated previously, this chapter adopts a broad usage of the term irrigation. Most African rice production systems with partial control of water application or drainage would be excluded from the irrigated category in all classifications. They are included in the discussions which follow to illustrate the range of options for intensification that should be considered for African environments. The reason that less than full control systems should be considered is that there are few instances in Africa where irrigation affords full water control. Therefore, one approach is to consider even areas with rudimentary water control as "irrigated." This approach is especially valid when the trend in land use is to greater water control over time.

African rice production systems can be contrasted with those of Asia by examining the general underlying complex of climate, soil, biological and human factors which determine productivity potential at a given location. In Africa the types of rice culture, soil conditions and perhaps more importantly, the biological evolution and low technological level of agriculture, have given rice to rice ecosystems very different from their Asian counterparts. Distinguishing traits include:

- The dominance of rainfed production over 80 percent of the rice surface area. In Asia there is a closer balance between the 49 percent of rice land which is termed "irrigated" and the 51 percent which is not (IRRI, 1982).

- Over half of the total rice area in Africa is dryland in IRRI terminology. In Asia this type of rice culture accounts for only a little over 8 percent of the rice area (IRRI, 1982).

- Africa has a much higher proportion of strongly leached and weathered soils and almost none of the volcanic derived soils found in Asia (Sanchez, 1976). Soils in Africa are low in fertility and very permeable. Asian soils have a greater proportionate area of more fertile and heavier-textured soils conducive to puddling.

- Africa lacks the extensive high mountain zones which in Asia sustain stronger perennial flows and provide significant amounts of weathered minerals to downstream soils.

- Africa is a site of origin of a different rice species

O. glaberrima, cultivated for 3,000 years. While the Asian O. Sativa varieties have been in Malagasy for over a thousand years and in West Africa for 400 years, a different weed, insect and disease complex has evolved (Carpenter, 1978). Asian concerns of bacterial blight, tungro virus, leaf hoppers and planthoppers are absent or not yet damaging (Buddenhagen, 1978).

- The technological level of rice production in Africa is generally much lower than in Asia. Population density is low; land use is extensive. Rice fields are part of medium to long fallow land rotations. The fairly well-defined classes of rainfed shallow and deep water systems with high to moderate water control common to Asia have not yet been established in Africa to any real extent.

- The intermediate input mix in Africa is very different from Asia. Missing from most of Africa are the cheap sources of motive force, water buffalos, which facilitate many of the key tillage operations in humid, lowland Asia. Tryponosomiasis prevent their introduction. Puddling and transplanting play a minor role in African rice systems. Seed, fertilizer, pesticides and machinery are in short and costly supply in Africa. Rice growing areas are generally remote from the sources of input supply and main markets. Transport networks are poorly maintained and operated and expensive to use (Pearson et al., 1981).

- Lowland African production environments are often disease and parasite infested, reducing both human and livestock ability to live and work in them. Trypanosomiasis, onchocerciasis and schistosomiasis, for example, have all reduced the habitability of good rice environments. Water control that leads to longer periods of standing water increases the prevelence of these diseases, thus increasing the need for monitoring and control (Lee and Maurice, 1983; USAID, 1982).

- Finally, there are few truly rice-based cultures in sub-Saharan Africa. Parts of Malagasy and some lowland zones along the West African coast provide exceptions to this statement, but most farmers who grow rice do so as part of land use patterns that include extensive areas of "dryland" cereals, grain legume, and root crops. (Upland and rainfed production are more common terms for non-rice specialists. Dryland production is a phrase generally reserved for semiarid or arid lands by non-rice-centric agronomists.)

Rice Production in Africa

Rice is a rainfed upland crop in much of Africa. Over half of the rice grown is grown under rainfed freely draining conditions. The most important exception to this general rule occurs in the river floodplains, deltas, valleys and coastal swamps. The latter environments are the main production sites of Africa's own cultivated rice species, O. glaberrima and the wild rice species which plague current production (Chambrolin, 1978; Carpenter, 1978). The Asian cultivars of the species O. sativa appear to have arrived on Madagascar and the East Africa Coast a few centuries B.C. and in West Africa about 1500 A.D. (Carpenter, 1978).

Upland, floating and swamp types exist for the principal domesticated rice species, O. sativa and O. glaberrima. O. sativa varieties are grown under varying degrees of water control from none to full. Consequently, there is a wide diversity of growing regions, practices and cultivars. However, rice is the main cereal foodstuff of the population of only a few countries--Sierra Leone, Liberia and the Malagasy Republic. Half a dozen other countries have major rice production zones which place rice as the third or fourth major cereal crop grown--Mali, Nigeria, Zaire, Guinea, Tanzania and the Ivory Coast (Winch, 1978).

Farmers have adapted production systems to a wide range of sites, mangrove swamps, coastal freshwater swamps, drainage catenas, river valley floodplains, lake recession lands, inland swamps and bottomlands and altered sites with traditional impoundment and drainage structures to improve production. More recently, formally engineered structures have been introduced to achieve higher levels of water control than was possible under traditional practice. While the rice subsector has shown frustratingly slow progress relative to Asian experience, it has been far from stagnant. Average yields in the major producing countries more than doubled over the last two decades.

However, progress in terms of yields and production has been slower than the blistering pact of consumption as population has increased rapidly, become more urban and changed its eating habits to include more rice and wheat. There are many factors involved in the failure of the rice sector to match demand. Among the more important ones are:

- Most programs of research and development of rice, even in traditional rice areas, started from assumptions of transformation of production systems from low water control to full water control. They assumed a full range of supporting services, which in turn carry their own assumptions about infrastructure, management, organizational procedures and policy.

- The Green Revolution in rice production and subsequent developments in Asia and elsewhere have led to price shifts which make much of African rice production noncompetitive at current productivity levels and transportation costs.

- Political and organizational shifts have disrupted research and development efforts.

- Until fairly recently there have been almost no attempts to examine rice as a subsidiary element of local cropping systems, rather than as the dominant crop of vehicle for cropping system transformation.

- Only fairly recently have systematic reviews of research and development strategies have been made that begin to permit reasonably fair ranking in physical, economic, social and managerial terms, of priorities, constraints and potential for rice production.

The Agronomics of Rice Production

The following sections discuss the rice production systems in Africa from the agronomic perspective. Special emphasis is placed on the research strageties employed to improve rice productivity. The improvement strategies employed to date have been combinations of what might be called "agronomic building blocks." These include:

1. Varietal Improvement;
2. Water Management;
3. Soil Management;
4. Weed Control; and
5. Pest Control.

Research programs and development projects have addressed most of these elements of agronomic strategy, and emphasis on one or more of them shapes site-specific strategies. For example:

1. Focus on cultivar improvement, water control and tillage in the Delta area of the Niger River;
2. Main emphasis on cultivar improvement, soil management and pest control in the Casamance River Basin of Senegal;
3. Wholesale transformation of farming systems to full water control, mechanization and high input use in the Lower Senegal River Basin in Senegal, the Office du Niger in Mali and the SEMRY scheme in Cameroon; and
4. Management of soil salinity, acidity and fertility and cultivar improvement in coastal mangrove swamps in West Africa.

Except in the cases of transformation of farming systems to full water control or the implantation of rice schemes in new areas, varietal improvement, water control, soil management, and mechanization tend to make up the main elements of rice intensification strategy.

Varietal Improvement. Chambrolin (1977) breaks the history of lowland rice varietal improvement into three periods:

1. Collection of adapted land races of *O. glaberrima* and *O. sativa* up until 1946 (yield potential about 1 t/ha);
2. Selection of pure lines of land races of *O. sativa* and crosses with introduced materials evaluated for response to fertilzer during the period from 1946 to 1966 (yield potential 5 t/ha);

and

3. Introduction of semi-dwarf HYVs and selection based on responsiveness to higher input levels, especially higher nitrogen, from 1966 through 1976 (yield potential up to 10 t/ha for lowland and 6 t/ha for upland varieties).

Yield potential has been the dominant criterion for selection and subsequent release to production projects across all three periods. During the late 1960s and 1970s the importance of weighting selection criteria for disease, drought and insect pest reistance was recognized and incorporated into screening programs and breeding strategies (Buddenhagen and Persley, 1978). The approach of varietal adaptation of rice to diverse ecosystems is perhaps best exemplified by IITA, which has a unified approach for lowland and upland rice improvement (Virmani, Olufowote and Abifarin, 1978) and IRAT's work on upland rice (Jacquot, 1978). The trend appears to be toward more site-specific varietal improvement derived from closer analysis of the constraints operating in different production systems. This trend parallels IRRI work to develop varieties adapted to problem sites where deficient or excessive water and adverse soil conditions are constraints to production (IRRI, 1982, 1983). As pointed out in a standard reference on rice production, (Grist, 1975). the new approach may redress the relative neglect of upland rice and permit the realization of the potential for use of underexploited hydromorphic and flooded sites in Africa.

The interaction of site conditions and varietal selection can be illustrated with two examples of floating rice systems. One is the improvement of floating rice varieties by IRAT and IRAT's predecessors at the Ibetemi station near Mopti in Mali. (Mopti is currently the site of both a WARDA research station and Operation Riz-Mopti, a production project.) The other is a study of the screening of rice cultivars to varying degrees of soil hydromorphy without investment in water control structures on the M'Bos floodplains in Cameroon.

Floating and Deepwater Rice in Mali. There are three critical periods in the life of a floating rice plant. The first is establishment under essentially rainfed conditions when drought may cause mortality or reduce growth to the point that the plants cannot withstand flooding stress. Under conditions of good rainfall, weeds may overrun the rice stand if the flood does not arrive soon enough to control them. The second critical period is the arrival of the flood. The rate of flooding may exceed the ability of the culm to elongate or the depth of flooding may produce stems which lodge at flood recession. The third critical period is flood recession. Too early or too rapid a recession may lead to lodging.

Starting after World War II, the Ibetemi farm and research station in Mali began experimentation with improved water control by constructing gated impoundments along the Niger River. The impoundments were designed to provide adequate water for rice growth, in nine years out of ten, through control of the earliest date and rate of flooding, depth of flooding and date and rate of flood recession. Researchers collected and compared land races of O. glaberrima and O. sativa and made introductions of Vietnamese floating rice types selected at the Kankan Center in Guinea. Three O. sativa introductions were selected for multiplication and extension before 1960.

IRAT took over the station in 1962 with the objectives to improve seed quality, to research white and non-shattering varieties, to study the adaptation of varieties to different depths and rates of flooding to determine their adaptive range and to maintain the glaberrima collection. Yield potential was increased from 2 t/ha to 4 t/ha.

From 1964 to 1974 improvement research focused on selection of the most fertilizer responsive varieties, their adaptation to local water regimes and breeding work. Breeding concentrated on crosses between floating and erect varieties and irradiation of both sativa and glaberrima germplasm. No success was achieved with glaberrima material hybridization or induced mutations. O. sativa selection and hybridization led to identification of three floating and several tall straw non-floating varieties with yield potential of from 3 to 5 t/ha for floating and 4 to 7 t/ha for nonfloating varieties under shallow water and good management conditions (Martin, 1976). Site variety trials were performed to determine which varieties were best suited to the varied flood regimes and degree of water control along the river.

While little progress was made in improving indigenous O. glaberrima varieties, the researchers at IRAT recognized the desirability of a number of traits of this species. Under conditions of drought during establishment, rapid flooding or stem borer attacks, the more rustic glaberrima varieties outperformed the sativa introductions. At the end of nearly 30 years of work, the plant ideotype that researchers had developed possessed many of the traits of the indigenous rice species along with the higher yielding character of sativa selections. Transition to breeding work on drought, flooding and borer resistance using glaberrima germplasm did not occur, as the IRAT station closed at about the same time the WARDA station at Mopti began operations.

The IRAT materials remains the mainstay of both research and production at Mopti and throughout the floating rice zone of the Inland Delta of the Niger. WARDA has yet to introduce significantly better varieties for floating conditions (Lewis, 1983). Instead, steps have been taken to increase water control to permit the use of fully irrigated varieties or the long-straw selections that can withstand flooding depths up to 60 cm.

Flooded and Pluvial Rice. The second example is from an IRAT study of the potential for the introduction of rice into cropping systems on upland and flooded land in the M'Bos plain of Cameroon (Seguy et al., 1976). The study opted for the adaptation of rice production to existing and variable natural hydrologic conditions as a less costly method than the construcion of irrigation and drainage infrastructure. Upland cropping of rice in rotation with other cereals and with legumes was studied at the non-flooded zone. In the flooded zone researchers divided the flooding cycle into the preflood period of rainfed cultivation, flood and recession. Rice varieties with growing cycles of the duration of each of these three periods were identified and tested in direct seeded and transplanted plots. These varieties were early medium straw upland varieties from Brazil and a range of floating and medium straw upland and irrigated varieties from Mali, Senegal and Asia. The researchers concluded that about 13 t/ha-yr of rice could be produced using a double-cropping system with improved management practiced in the floodplain. Blast and lodging resistance were identified as priorities for further varietal improvement.

The Mali and Cameroon experiences, both concerned with floating rice, show the different rice ecosystems that result from very different topographies and climatic conditions. The Mali rainfall runs about 400 mm/year, while nearly 1,500 mm falls in the M'Bos plains. The higher rainfall at M'Bos makes it possible to double-crop and necessary to have varieties with both floating and non-floating habit to achieve the double-cropping objective.

As Buddenhagen (1978) has pointed out, the selection of rice varieties should be a function of the rice ecosystem as defined by four general parameters:

1. The type of rice culture;
2. Climate and soil conditions;
3. The biological evolution of the region; and
4. The technological level of agriculture and the human culture in which it is based.

When these parameters are broken into subunits, the matrix of rice ecosystems in Africa is a large and complex one. Each of the cells of the matrix defines selection criteria that should be applied in screening and improvement programs. The two examples given show a little of the variation in selection criteria that occurs for the same type of rice culture under greatly different climate and soil conditions. The work in Mali fortunately took into consideration a wide range of flooding depths and permitted the screening of varieties that performed well in the shallower floods and more fertile soils of the site in Cameroon.

Mangrove Swamps. Mangrove rice growing presents another long-term study of rice variety development. Soil constraints are the principal elements of the ecosystem which limit rice production. Combined with saline water intrusion in coastal environments, it is clear that either major development and recurring management costs have to be paid or varieties and practices have to be adapted to unfavorable conditions. Seasonal or artificial draining of these soils leads to oxidation of sulfates and a drop in pH to 2 or 3. Establishment and growth of rice plants may be hindered by the low pH itself, or by toxic concentrations of dissolved aluminum, iron, hydrogen sulfide, carbon dioxide and organic acids during the first few weeks of reflooding. In coastal environments these soils may not dry out and acidify, but salt water intrusion during the dry season creates an unfavorable environment for rice plant establishment. Rice farmers must wait until rainfall and river flows leach salts to the point where transplanted crops can survive (Van Breeman, 1980).

Varietal improvement has been under way for flooded mangrove areas since 1934 at Rokupr station in Sierra Leone. Additional work occurred in the Gambia, Senegal and Nigeria. Starting from selection of floating rice varieties from local material and introductions, these centers initially focused on high yielding, well-adapted, photoperiod sensitive, long duration and vigorous growing varieties. Hybridization work produced much breeding material, but few varieties were found that performed as well as local or exotic selections. Interspecific crosses between O. sativa and O. glaberrima were hampered by high sterility, segregation into advanced generations and apparently poor combining ability for desired traits (Virmani, 1978). Mangrove swamp rice improvement has continued to rely upon selection and limited hybridization, but from an expanding germplasm base from Asia facilitated by links to WARDA and IRRI. Selection is grouped for freshwater and for saline areas at Rokupr. Yields vary greatly from fresh to saline conditions. Improvement from local land rice yields of 0.8 to 1.0 t/ha to yield potentials of 3 to 4 t/ha have been achieved. Concern over the apparently growing incidence of borer and diopsid damage and blast and blight diseases has prompted increased work on selection for varietal resistance (Lewis et al., 1983; Virmani et al., 1978).

Shallow Swamp and Irrigated Rice. The third major rice ecosystem for which varieties have been selected is shallow water swampland. Drought resistance, shorter maturity cycles, fertilizer responsiveness, blast resistance, borer and diopsid resistance are important selection criteria for this group of cultivars. In deeper water areas where stagnation occurs, or on marine alluvial deposits, tolerance of iron and aluminum toxicities is needed as well. These production areas are usually located in the more humid zones of Africa where growing conditions more closely approximate irrigation water regimes. Varieties developed for irrigated conditions tend to do reasonably well in non-toxic swamp conditions.

Most of the rice varieties used in swampland and irrigated ecosystems have been introduced and bred under the auspices of IRAT and the national agricultural research institutions in Francophone West Africa, Rokupr Station in Sierra Leone, the Liberian Agricultural Company and Suakoko in Liberia, Badeggi Station in Nigeria, IITA at Ibadan, WARDA and IRRI. The series of Taiwan rice missions in the 1960s and early 1970s had a material effect on varietal introductions for both research and extension purposes (Chambrolin, 1977; Virmant et al., 1978).

There have been progressive waves of introductions of materials from Asia. Some of the earlier introductions made in the 1960s have proven to be the most durable. Taichung Native I (TN 1) and Jaya (a late Indian selection from TN 1), I Kong Pauo, Taichung 178, Tung Lu and TS 23 are still important varieties and crosses provided the second major wave of varieties to be introduced for swamp and irrigated production. Among these, IR 8, IR 5, IR 6, IR 20 and IR 24 have been grown in major rice areas. IR 8 has been dropped out of many areas due to disease and milling and taste problems. IR 5, IR 20, and more recently, IR 422, have been used in improvement and production programs. Production from any of the IRRI varieties has not been stable over time in the African setting, while the older introductions seem to have lower but generally reliable performance. However, their agronomic traits make them vital components in new varietal development (Chambrolin, 1977; Virmani et al., 1978).

Water Stress Tolerance: Upland versus Lowland Types. Africa possesses numerous local and improved dryland or upland varieties which have shown good tolerance for drought conditions. The intermittent flooding and drying that occurs in many rice fields leads one to ask if dryland varieties might be better suited to low water control situations. The answer appears to be a qualified no. Across water stress studies done under irrigated and rainfed conditions, the semi-dwarf lowland HYVs generally outperform the traditional upland varieties (Le Buanec, 1976; Sanchez, 1976). As water requirements for upland and lowland rice plant transpiration are about the same, there is no apparent advantage in terms of water savings from the use of upland varieties in flooded field conditions or under high rainfall regimes.

However, Change and Vergara (1975) point out that there is a wide range of drought resistance traits in rice that reflects the environments of selection. Rice varieties from some intermittent wet and dry growing systems carry with them a measure of the deeper and coarser rooting characteristics of the dryland varieties. They also retain moderate to high tillering ability, which enables them to recover from drought and produce higher yields if late rains are available.

Drought resistance literature for rice has a confusing history because of the wide mix of methods and plant materials used. Drought avoidance, recovery from drought effects and drought tolerance appear to be associated with different plant types (Alluri et al., 1978). The different components of varietal resistance to drought are studied using soil water potential gradients obtained on natural toposequences or artificial chambers (Lal and Moomaw, 1978). Quantification of drought resistance and yield relationships should permit the identification of varieties which will perform well under a variety of water control regimes in different climatic settings. This approach is being followed at IITA, where lowland and dryland varieties are developed using transect screening for soil water regime and a variety of agronomic traits (Chabrolin, 1977).

Since many rice production schemes have poor water control, it is worthwhile to consider the use of certain rice varieties with intermediate drought resistance. Under high rainfall conditions in Ivory Coast, some of the IRAT dryland rice cultivars with medium height and good lodging resistance have a yield potential on the order of 7 t/ha (Jacqout, 1978). In high insolation environments, such as those found in the Sahel, improved dryland varieties may offer greater yield stability on perimeters which have water control difficulties. Taller, traditional varieties may also offer associated disease and pest resistances, better competitive ability with aerobic weeds and slightly greater flexibility in crop management could be anticipated for arid and semiarid sites where rice is the preferred crop. An evaluation of the Bakel Small Perimeters Project in Western Senegal provides some support for this approach on the lighter texture soils of the project (Keller et al., 1982). This approach would also fit with economic recommendations for an incremental approach to transformation of river basin farming systems from flooded, recessional and rainfed cropping to full water control (Sparling, 1981).

Insect Pest Resistance. Soto and Siddiqui (1978) reviewed the status of insect pest research in Africa. The insect pest complex contains many species that are different from those found in Asia. One of the reasons advanced for this is the existence in Africa of different native wild and domesticated rice species. The low insect damage to rice under smallholder conditions was ascribed to the low density and intensity of rice production, varietal resistance and the assumption that potential pests and their predators were in relative balance.

There is some evidence that native species and local varieties have resistance to stem borers and dipterids, the major rice insect pests in Africa. However, there have been few studies which documented levels of resistance of their apparent mechanisms. Martin (1976) showed that Milian collections of floating rice of the species O. glaberrima had on the average only 5 to 15 percent of culms attached by Chilo and Maliarpha borers. O. sativa varieties averaged 40 to 80 percent attack incidence. Plant cycle lengths were different--O. sativa varieties were in the field longer--but this confounding factor was thought to only partially account for the differences. Several years of field studies in the Casamance region in southern Senegal showed that O. glaberrima had high resistance to Diopsis thoracica (Vercambe, 1981). Few egg masses were laid on the indigenous rice species. Resistance varied across O. sativa cultivated. Some had few egg masses; others had many egg masses but little dead heart; and others had significant growing point damage but recovered, apparently due to stimulation of heavy tillering as apical dominance was removed by larval feeding.

IITA, IRAT, WARDA and national research programs have also identified and regularly screen for varietal resistance to borers and dipterids (Chambrolin, 1977). To date, the sterility and instability of interspecific crosses between O. sativa and O. glaberrima have prevented exploitation of the high levels found in the indigenous African species.

As irrigation of rice increases in surface area and in intensity, it has become clear that some "Asian" insect problems are surfacing. Brown planthopper damage at economic levels was reported from Ibadan, Nigeria in 1984 (Alam, 1984). This reporting and the appearance of Dipterid pests in greater numbers with double-cropping in Ivory Coast (Moyaï, 1982) indicate that past hypotheses about greater damage levels occurring with increased cropping intensity are being confirmed. Control methods other than resistance screening are discussed in a later section.

Disease Resistance. All major breeding and selection programs for rice in Africa include blaste (Pyricularia oryzae) resistance as one of their top priorities. Bidaux (1978) points to the rapid expansion of rice cultivation in West Africa as altering the host and pathogen balance. Larger rice areas are sown, less blast resistant varieties have been introduced and growing practices are extended that favor blast development. Because many different blast strains are found, researchers are concentrating on the selection of varieties with durable blast resistance. However, as Buddenhagen (1983) points out, there is a fundamental controversy about the ability to breed for horizontal resistance to avoid the collapse of resistance as new races of pathogens develop or are introduced.

High and Low Temperature Tolerance. Critically high and low temperatures for rice vary from one growth stage to another and also differ according to variety, duration of the critical temperature, diurnal change and the physiological status of the plant (Yoshida, 1977). Both high and low temperature limitations exist for rice growth in Africa, depending on climatic conditions at a specific location. Burkina Faso and Cameroon are sites for selection of cold tolerant varieties in collaboration with IRRI (IRRI, 1983). Screening for rice varieties that withstand temperatures higher than 35^{o} celcius at flowering is also a concern in many Sahelian and Sudanian zone countries.

Regional Coordination of Varietal Improvement. WARDA has established a ranking of stations for their appropriateness as sites of first evaluation of adaptiveness of rice varieties to rainfall regimes, type of cultivation and resistance to physical, chemical and biological constraints to productivity (Wills, 1977). IITA and IRRI provide additional scientific coordination. IRAT provides a measure of coordination among the national rice programs working in Francophone countries with a special concentration on dryland rice production.

Evaluation of WARDA's role in rice research and development lauds its work in exchange of information, germplasm and trials. The institution has played a major role in the training of staff of national research programs. However, the coordinated varietal trials are seen by Lewis et al. (1983) as not leading to progress in identifying improved varieties for the diverse production environments of the 14 member nations. The regional subprograms for irrigated rice at Fanaya in Senegal; mangrove swamp rice at Rokupr in Sierra Leone; and deepwater rice at Mopti in Mali are characterized as having greater relevance for national rice production in those three countries than for general application to similar rice production systems in the region. The Lewis report is very favorable toward potential WARDA involvement in the upland rice research programs at Bouaké in Ivory Coast. A recent review of agricultural research in Ivory Coast upholds the pre-eminent position of the Bouaké in upland rice improvement (ISNAR, 1982). At the same time, the varietal improvement program is seen as perhaps too fundamentally oriented and definitely in need of reorientation to incorporate cropping and farming systems work.

Water Management

Water regimes for rice lands have been extensively described and used in the selection of rice varieties and development of rice-based cropping systems in Asia (Moorman and Van Breeman, 1976; IRRI, 1983). Water deficit at any period reduces yield to some degree (Yoshida, 1976), but yield losses may be insignificant in an economic sense if the deficit occurs at non-critical stages of plant growth (Grist, 1976). Rainfed cultivation is generally limited to areas with greater than 1,000 mm of rainfall (Yoshida, 1976) or where surface flows provide flooded conditions for growth. Average field water requirements for a transplant nursery, land preparation and crop irrigation are given as ranges of 840 to 1,240 mm (Grist, 1975) or 1,200 to 1,800 mm (Ilaco, 1981).

The field water requirement in full control systems is generally applied in one of three ways--continuous flow, rotational applications to maintain or top off water levels or intermittent irrigation which alternates flooded and dry surface conditions. IRRI research has shown that maximum crop yields can be obtained under conditions of soil saturation without standing water. However, the degree of system reliability needed for on-demand irrigation to avoid moisture stress is seldom attainable, either technically or economically. Sanchez (1976) reviews experimental data which shows that even moderate stress reduced yield in both lowland and dryland varieties. Rice is more susceptible to water stress than most crops. The practical available moisture range in rice may be between flooding and field capacity, according to Sanchez; flooding therefore provides insurance against water stress. Flooding is generally a preferred practice because:

1. Water stress is eliminated;

2. Control of aerobic weeds is easier; and

3. It induces a reduced soil environment which increases the availabilty of some nutrients as pH approaches neutrality.

This evidence argues for continuous flooding, if not continuous flow application (Sanchez, 1976). Other authors would argue that practical limitations imposed by water delivery schedules, water costs and perhaps the need for drainage to carry out cultural operations, make intermittent irrigation with its water savings more attractive (Grist, 1975; Ilaco, 1981).

In soils with high percolation rates and the potential for associated leaching of nutrients, puddling can improve water and mobile nutrient retention. Puddling, or the destruction of the topsoil structure by tillage of soil at high moisture content, breaks up soil aggregates, decreases non-capillary pore space, modifies bulk density, increases soil moisture retention, decreases soil moisture losses and induces reduced soil conditions without flooding (Sanchez, 1976). Puddling enables the benefits of flooding to be obtained with lower field water use. However, the increased time needed for soil drying, increased soil bulk density upon drying and the need for additional water and tillage power to regenerate topsoil structure are liabilities for farms on which a non-rice crop is planted in the puddled field. Also, in rainfed areas where early season drought is a problem, dried puddled soil may reduce growth in rice to the point where recovery is not possible and large yield losses occur (Sanchez, 1976).

The greater part of work on irrigation regimes, flooding and puddling has been done in Asia. Improved water management for rice is much more costly and difficult to sustain in sub-Saharan Africa. Traditionally, rice has been a crop of localized opportunity, relying on high rainfall, floods or advantageous topography to supply water. Low population density, low access to mechanical power, poor market access and agricultural technology of low productivity provided little pressure or opportunity for intensive water mangement--whether to compensate for deficient rainfall, protect against deep and rapid flooding or drain excess water.

The following sections trace some of the approaches to water control and their problems over a range of natural water regimes in Africa.

Floating Rice. Depending on the species and cultivar grown, floating rice can be subject to two or three periods of greatly different water regimes. Rice is broadcast or drilled and grows as a rainfed crop until the arrival of the flood, grows under floating conditions until flood recession and matures as a recessional crop or is harvested from boats in standing water. Rice land races of different maturity classes is grown according to anticipated flood levels and the need to prepare land for a recessional sorghum crop after the rice harvest. Small polders are constructed by farmers to gain some control over flooding rates and flood recession dates (USAID/Bamako, 1981). Most of the rice land races grown are *O. glaberrima* types.

Researchers from IRAT and project managers for Operation Riz-Mopti have oriented their work on water control toward progressive improvement that may eventually lead to full-water control (Vallée and Vuong, 1978; Martin, 1976; USAID, 1981). In the first phase, dikes and gates are constructed to regulate the rate of flooding and protect the rice against submersion for long periods by high river floods. Martin has shown that flooding rates should not exceed 5 to 7 cm/day. Thirty-day-old plants of improved varieties cannot withstand flooding rates of 10 cm/day for more than five days. Transplanting was ruled out as a practice because of the low flow rates required to prevent submersion damage to young plants--less than 1 cm/day--and the delay of harvests. Depending on position along the river and site topography, flooding depths range from 2.5 m to 30 to 40 centimeters. Improved deepwater varieties did not perform well when more than 60 cm of water was present.

In a second phase, complete water control with pumping of water from the river to supplement early season rainfall and avoid drought stress at crop establishment is expected. Fields would be leveled and most of the deeper water zones would be eliminated, permitting the greater use of HYVs and more secure investment in inputs. This phase has not been reached, even at the WARDA research station near Mopti (Lewis et al., 1983).

Rather curiously, the Action Riz-Sorgho Project in the Gao region misapplied Mopti station results to a project attempting to achieve complete water control with small-scale submersible dikes and transplanting. Lack of field leveling and the delay in both the rice crop and subsequent recessional sorghum crop brought about by the recommended practice of transplanting led to low adoption rates by farmers and the lack of success of the project (USAID/Bamako, 1981).

One strategy that has not been examined for the controlled flooding sites for rice production is improved management during the rainfed period of crop establishment. Specifically, examination of postharvest tillage and residue practices is an attempt to improve dry season storage and early rainfall infiltration would appear to be a logical extension of the partial water control approach followed to date.

Deepwater Rice. Deepwater rice production in Africa can be seen as an intermediate stage in water control between floating and shallow water/irrigated rice. In the riverine environments of Sierra Leona, water control is poor and improvements are more oriented to mechanized assistance to tillage operations. In the M'Bos Plain in Cameroon, varietal selection and mechanization of tillage operations have permitted yields of 4 to 7 t/ha without investment in infrastructure. In the inland valley swamps of Sierra Leone, partial water control is practiced by clearing land of stumps, partially leveling land and constructing dikes and contour bunds. The structures provide some control over the flooding and drainage of rice parcels. Paddy yields of 3 to 4 t/ha are about 30 to 50 percent greater than traditional swamp cultivation (Spencer, 1981). Water control is only part of a package of practices, including improved cultivars and fertilizer use, that contribute to high yields. Since transplanting is done, the improved deepwater rice production systems avoid the problems of rainfed rice plant establishment.

Mangrove Swamps

Water management in mangrove swamps ranges from uncontrolled tidal flooding to control of both fresh water and salt water application and pumped drainge systems. Touré and Arial (1978) describe the landscape of mangrove swamps in southern Senegal, the physical and chemical characteristics of the soil subunits and the suitability of the soils for rice cultivation. The availability of fresh water to leach salts from the soil horizon was found to be crucial. Farmers in the mangrove swamp zone traditionally rely on rainfall to leach salts sufficiently to transplant a rice crop, or construct polders and drains to prevent salt water intrusion and permit greater control over leaching of salts.

Attempts to improve water control in mangrove swamps must pay careful attention to fresh water and salt water application and drainage. Complete drainage and drying of mangrove swamps leads to strongly acid soil conditions, so there is a delicate balance between meeting the needs of rice plants during the growing season and avoiding drying and acidification during the dry season. Beye (1975) describes five years of work on drainage and desalination of a rice polder in southern Senegal. Fresh and salt water inlets were provided, along with gravity and pumped drainage systems. Under the rainfall and river flow conditions of the area, soil salinity was reduced to levels acceptable for rice production. During the dry season flooding with saline water of the polder soils was permitted to prevent acidification. Des Bouvrie and Rydzewski (1977) cite the Kobak and Kasawa pilot projects covering 3,000 ha in the mangrove swamps of Guinea which used improved bunding and drains to obtain average yields of rice of about 5 t/ha.

There are about 2.5 million hectares of mangrove swamp in coastal Africa (Schantz and Marbut, 1923). Under good management a portion of this area not subject to deep flooding could become productive rice land. The sustainability of good management practice on these lands has been questioned, not only in Africa but worldwide (Saenger, Hegerl and Davie, 1983). The danger of acidification or resalination in dry years, which would greatly reduce crop yields; creation of favorable habitats for schistosomes and other vector borne parasites and diseases; and exclusion of alternative uses for shrimp and fish have been cited as reasons to create reserve areas and proceed very carefully with development efforts (National Research Council, 1982).

Shallow Water Rice. In swamp areas with moderate inflows from watersheds and streams and along rivers, traditional water control has been practiced. Except in areas where upstream storage reservoirs or river diversions provide a more reliable surface flows, the shallow water rice areas are subject to intermittent wet and dry periods which adversely affect rice establishment. These areas also frequently are part of landscapes which contain a gradient in water regimes from flooded through hydromorphic to freely draining. Bertrand et al. (1978) and Moorman and Van Breeman (1978) discuss these drainage catenas.

As these sites are valuable parts of farming systems that use many land classes for linked crop and livestock production, traditional water management strategies are not always based on favoring rice production. Late dry season grazing needs, for example, are sometimes seen as more important than land preparation for rice. Therefore, work to repair bunds and drains to manage water levels for early transplanting may take second priority to maintaining livestock conditions for animal traction or meat and milk production. The work of Traverse (1975) in the Lower Casamance River Valley in southern Senegal suggests that livestock be excluded or otherwise dealt with to permit better use of available soil and water resources for rice production. Both sandy and clay textures in the zone studied produced yields on the order of 1.5 t/ha. On the sandy sites, early direct seeding of improved varieties after plowing and fertilization gave demonstration plot yields of about 4,400 kg/ha. On the heavier textured clays, fairly complete water control and intensive use of animal traction, fertilizers and pesticides were used over a three-year period to permit rice double-cropping. The first crop was rainfed, shallow water. The second crop was irrigated during the dry season. Rainy season yields averaged 4,300 kg/ha. Dry season yields averaged 6,100 kg/ha.

Full-Control Irrigation. There are full-control, irrigated rice projects in almost every country in sub-Saharan Africa. As Moris et al. (1984) point out, the use of the term "full-control" is inappropriate to many schemes. Variability in water availability, main system operations, drainage and on-farm water management all contribute to less than full control. The consequences are usually reduced utilization of constructed facilities, cropping intensities that are much lower than designed, and yields that do not meet expectations of planners or farmers.

An assessment of irrigated agriculture in Mauritania outlines some of the trends in full-control perimeter utilization (Humpal et al., 1983). Average facility utilization calculated as the percent constructed command area that was cropped ran about 61 percent, with a modest increase to 67 percent if double-cropped area was included. Newer irrigation perimeters generally had higher cultivation intensities than older ones. Table 33 gives trends in cultivation intensities for small-scale perimeters constructed and managed in the Gouraye sector with assistance from private voluntary organizations.

TABLE 33

CULTIVATION INTENSITIES IN THE GOURAYE SECTOR SMALL IRRIGATED PERIMETERS

Year	1978	1979	1980	1981	1982
Cultivation Intensity	0.6	1.45	1.48	1.84	1.49

Source: Humpal et al., 1984.

In these run-of-the-river pump schemes, cultivation intensities increased as new perimeters were constructed from 1978 through 1981. The big reduction in cultivation intensities in 1982 resulted from the inability of farmers to obtain credit to finance production. Farmer inability to repay old credits was caused by pump breakdowns, which the central irrigation agency was unable to repair in a timely manner. Although these 20 to 40 hectare perimeters were not major engineering works, the small-scale of operation did not prevent poor main system operation and water applications were not very efficient. Fields were flood irrigated for broadcast rice planting. Poor leveling of fields was noticeable. Corn and sorghum were grown on high spots, while flooded rice occupied the low spots.

Downstream from the Gouraye small-scale perimeters is the Gorgol Pilot Perimeter. Designed for a 7000 ha net command area, the actual command area was 3800 ha in 1980 (RAMS, 1980). Water control at this site was not a problem of water delivery, but of flood control. The project site is in a minor flood bed along the Senegal River above the confluence with the seasonal Gorgol River. Protective dikes have proven insufficient to control peak floods. No provisions for excess surface water pumping were made in the design of the project. Rice crops have had to be replanted on several occasions. Gorgol is one of three major irrigation perimeters along the Senegal river (SONADER, 1981). The second, covering 920 ha at Boghé, is also in a floodplain. The third and largest, covering 1,420 ha at M'Pourie, is constrained by seasonal salt intrusion from the Senegal delta to a single crop each year.

On the opposite bank of the Senegal River there are also small perimeters, constructed and managed with the assistance of SAED (Société de l'Aménagement et l'Exploitation des Terres du Delta et de la Vallée du Fleuve Senegal). Tuluy (1981) found that water delivery was reliable, that rice yields of 4.75 t/ha were being achieved, and that double-cropping with maize and vegetables was successful. SAED support to maintenance and repair operations permitted good main system management, and farmers had leveled their small 0.20 ha plots.

Upstream from Matam there is another series of small-scale perimeters, in a higher rainfall environment at Bakel. Rice yields were similar to those at Matam. However, water supply was judged to be unreliable, operations cost was high, conveyance efficiencies were low, infiltration rates high due to poor site selection, land leveling had not been done and farmers were shifting some land to maize and other less water demanding crops (Keller et al., 1982). Based on an examination of the environment, crop production systems in the area and the five-year history of the perimeters, these authors recommend a series of engineering, agronomic and management changes to improve the productivity and return of the perimeters. In the water management area alone, consideration of several factors indicate a range of irrigation options for the Senegal River Basin that are yet to be explored (Keller et al., 1982). They include:

- Piped or lined canal conveyance;

- Examination of water application methods, including intermittent flooding and sprinkler irrigation;

- Hybrid systems of full irrigation, supplemental irrigation and rainfed production in a contiguous layout;

- Production of rice under non-flooded upland crop irrigation regime; and

- Modification of cropping patterns to include a greater share of upland crops and extend the surface area cultivated.

It would be fair to say that adoption of a monolithic continuous flood rice production model in the Senegal River Valley is one of the biggest technical design flaws contributing to lack of perimeter success. Rice is far from the best crop selection under the conditions of evapotranspirative demands and percolation losses of water that prevail.

In the Ruzizi Valley of Zaire rice has been cultivated in flooded swamp conditions since the arrival of Arab traders in the 19th Century. Full control flood basin irrigation was introduced by the Belgians in order to use solonetz soils (dystric and eutric natrustalfs) that occupied a portion of the valley (Jurion and Henry, 1969). In contrast to the Senegal River Basin examples, rice was the best crop adapted to these poorly drained soils. Available water studies were used to adjust water application rates. Maximum yields were obtained by irrigating when soil moisture levels fell to 60 percent of saturation values (INEAC, 1959). Yields averaged about 4 t/ha on the richer soils and 2.5 t/ha on the poorer soils (Dewez and Catzeflis, 1959; Vandenput, 1981).

Humphreys (1981) describes three types of irrigation in Ivory Coast:

1. Lowland irrigation by diversion from small streams into small valleys;

2. Dam and storage reservoir-fed systems; and

3. Run-of-the-river pump schemes.

While theoretically able to support double-cropping, none of the three do. In the lowland case, streamflows do not provide sufficient water for a dry season crop. The dam schemes have insufficient storage capacity and percolation rates have been higher than anticipated. The pump schemes suffer from highly variable river flow, poor pumping and conveyance efficiencies, and loss of water to deep percolation.

These three examples illustrate that many irrigation schemes are designed and constructed with less than necessary understanding of soil, water and climate data. Des Bouvrie and Rudzewski (1977) make this point. However, they concentrate on the need for region-wide collection of meteorological and hydrologic data. Given the current density of irrigation perimeters in Africa, it should be possible to more carefully design the new generation of perimeters based on the empirical evidence provided by the pilot projects. Design of a system that makes best use of available soil and water resources and mitigates natural constraints takes a greater effort in site specific investigation. This point seems to be particularly true of small-scale perimeters, for which cursory site identificaton and design surveys often are done.

A second key point is that site identification, design and construction of full control irrigated rice perimeters seem to be as poorly done in humid as in semiarid to arid conditions. In the more arid environments designers underestimate flood levels and site perimeters on soils with high percolation rates. In more humid environments they seem to overestimate water availability for dry season cropping and site perimeters on porous soils. In both settings small- and medium-scale perimeters suffer from conveyance systems with high unreliability and low efficiencies. Scheme land leveling operations are often crudely done for these classes of perimeters, and on-farm basin leveling is seldom done accurately.

Under these main system operating characteristics, comments about the over-utilization of water by farmers with little irrigation experience need to be discounted by some sort of system unreliabilty risk factor. As Kaller (1982) points out, the Bakel farmers became very efficient irrigators and utilizers of microdrainage patterns in their fields when water delivery was unreliable. That they took five years to figure out how to successfully grow the wrong crop in the wrong place perhaps says more about the inability of designers to adapt irrigation design principles to the specific conditions of Africa than it does about African ability to develop irrigation skills. Common wisdom adopts the opposite viewpoint (World Bank, 1981), but may need revision.

Soil Management

In this section an attempt is made to discuss soil management practice as it relates to water availability and soil fertility in rice production systems.

Soil Management During Rainfed Periods. Flooding and puddling were discussed in the previous section on water management. While there is not an absolute need for standing water to produce maximum rice yields, there are other reasons for doing so, e.g., to control aerobic weeds, facilitate leaching of salts, prevent acidification of mangrove soils or reduce the likelihood of intermittent wet and dry periods that leak nitrogen from the fields. Puddling is seldom employed in Africa, with the exception of Madagascar. It is possible but extremely difficult to puddle many of the oxisols, ultisols and alfisols with lighter texture (Sanchez, 1976). Lack of motor power and use of rice paddies for rainfed and recessional crops is a partial explanation. Inadequate control of water supply is probably a bigger factor.

It is important to realize that most rice lands and rice plants are rainfed up until the crop is well established. Land is prepared dry or after rainfall has softened it sufficiently for tillage. Nicou and Charreau (1980) point out that the high intensity rainfall that occurs at the beginning of rainy seasons causes crusting and runoff of water that would otherwise be stored in the soil. Many of the lighter texture soils also develop mechanical impedance to root penetration after a few years of crop production. Apparently because the low water control systems are viewed as transient to full control systems, there has been little attention paid to soil management during the rainfed period. Some approaches suggested by the literature from dryland agriculture and some rice studies are:

1. Tillage early in the growing season to increase rainfall infiltration and reduce mechanical resistance to weed growth (Nicou and Charreau, 1980);

2. Tillage after harvest to improve cloddiness, with the aim of reducing soil loss from wind erosion during the dry season, reducing water erosion at the beginning of the rainy season and shortening the time to first tillage by hand or animal drawn equipment (Henderson, 1979);

3. Tillage at the end of the season to incorporate residue; and

4. Tillage after harvest to reduce weed growth and conserve soil moisture.

The problem with all of these approaches is the need for motor power; they can be practiced only where animal traction or tractor services are available.

Fertility Management. Fertility management is a function of soils, past use, water management, proposed cropping intensity and availability of inputs, together with the money and farm power needed to employ them. A wide range of practices has been followed.

During the 1940s and 1950s research pursued an organic approach to fertility management at the same time that commercial fertilizers were being tested. In Zaire four approaches were tested on-station and on farmer holdings (Jurion and Henry, 1969; Dewez and Catzeflis, 1959; and INEAC, 1959):

1. Use of farm yard manure at doses ranging from 10 t/ha to 45 t/ha. Yields were increased, but the practice was uneconomical and made more so by the use of dried manure. It was unclear whether the main effects were related to nutrients or to modified physical properties.

2. Green manures. *Mucuna utilis* gave the best results with six-month fallows equivalent to longer fallows of other crops.

3. Fallows of pasture species. Effects of different species varied. One year after the pasture fallows yield effects were about the same. In year two after fallows the leguminous fallows generally gave better results.

4. The "practical" approach. Maximize reincorporation of weeds and crop residue with a potential short green manure crop of *Mucuna*.

All of these approaches required mechanization and did not provide yield responses of sufficient economic value to provide an incentive for farmers to switch from natural fallows to managed fallows (Sanchez, 1976). Some benefits from rotation with crop legumes were reported from Zaire (Focan, 1961), but rice yields could not be maintained by rotation alone.

Application of mineral fertilizers to rice crops has been reviewed by Grist (1975), Sanchez (1976), Poulain (1976), Martin (1976) and Jurion and Henry (1969). In most instances nitrogen is the primary limiting nutrient, with phosphate in second position and occasional deficiencies of zinc and magnesium following. The variable effects of nitrogen applications on yields have been related to soil fertility differences, the susceptibility of older varieties to lodging at moderate nitrogen levels, application of inappropriate nitrogen forms to wet rice systems and the leaching characteristics of the soils investigated. Generally, ammonium-based fertilizers or urea are used in flooded conditions. Intermittent reduced and oxidized (flooded and nonflooded) states should be avoided to prevent loss of nitrogen. Application and mixing in the root zone and water applications to avoid leaching are recommended by Sanchez (1976) as practices to avoid nitrogen losses which are used too infrequently.

Poulain (1976) studied nitrogen response curves in rice grown under flooded, full control and dryland conditions. For irrigated short stature rice, he recommended split applications at tillering and panicle formation. For tall varieties, a single application half that for irrigated rice was advanced.

Weed Control

Annual Oryza barthii and perennial Oryza longistaminata wild rices are generally recognized as the most serious weed pest of all rice production systems that are irrigated or flooded for long periods of time. In recessional systems, cutting of annual wild rice grown during a flooded fallow; plowing at the beginning of the rainy season with three harrowings; and plowing before flood arrival, followed by late plowing at the beginning of the next growing season, kept wild rices in check on controlled flooding schemes in Mali (Vallee, 1980). Perennial wild rice is best controlled by plowing, which brings tubers to the surface to be dessicated during the dry season.

Under irrigated conditions annual red rice has become a serious pest (Keller, 1982; Deuse et al., 1980). On small perimeters manual control is possible. Avoidance of reinfestation has been done through careful control in seed selection and weed seed screens (Martin, 1975). Deuse et al. (1980) give several methods of control:

- Use of early varieties which flower and mature before red rice sets seed;
- Use of cultivated fallows;
- Rotation with sorghum, maize and wheat;
- Preirrigation followed by harrowing--will not eliminate dormant wild rice seed;
- Seed cleaning to eliminate red rice--an expensive process;

- Rotation with perennial forage plants;
- Grazing of native stands and fallow fields by sheep and goats; and
- Herbicide use with antidotes for cultivated rice--oxadiazon was the most promising herbicide.

Weed control practice during crop establishment under rainfed conditions should follow good dryland rice practice. Merlier (1982) discusses prevalent weed species and the changes in their relative abundance from land clearing to alter periods of field history. There is heavy emphasis on deep tillage to eliminate Imperata cylindrica and other species. Control of weeds during the second month after germination is identified as the critical practice for dryland production weed competition during the second month of crop growth reduced yields 70 percent. Oxadiazon showed its relative effectiveness in rice weed control. Weeds and their control in dryland, hydromorphic and lowland rice are reviewed in Akobundu and Fagade (1978).

Insect Pest Control

Soto and Siddiqi (1978) review the status of rice insect pest understanding and control practices. Emphasis is placed on the need to understand the biology, ecology and distribution of rice pests as a necessary preconditon to the development of effective insect pest management strategies. Brenière (1976) provides an examination of the taxonomy and distribution of the principal borers in West Africa. Vercambe (1982) presents an elegant study of the economic ecology of the stalk-eyed fly, showing that adherence to extension recommendations to plant rice crops early will lead to greater damage. Analysis of the life cycle, habitat and seasonal population behavior led to recommendations on cultural practices and varietal selection to avoid damage. Bonzi (1982) and Moyal (1982) discuss the increasing incidence of borers, whorl maggot and rice gall midge on irrigated rice crops in Burkina Faso and the Ivory Coast. Brenière (1981) and Brenière and Bordat (1982) discuss the role and potential of biological control of cereal pests, including rice, in Africa.

It is fairly clear from the literature that, with a few notable exceptions, the economic behavior of most insect pests of rice is not well understood in Africa. This lack of understanding means that cultural practices to avoid or reduce economic damage levels will be slow in developing. Vercambe's economic (1982) study took seven years to complete. Release of borer predators has been tried after predator rearing in Europe, but biological control is still in its infancy in Africa. Even if technically possible, an economically feasible program of biological control is probably far on the horizon. In the absence of solid information, Brenière advocates a pragmatic, empirical, approach, including:

- Determination of the economic threshold of damage;

- Determination of the economic feasibility of the treatment;

- A treatment calendar based on susceptible periods during insect life cycles; and

- Minimization of the risks of disequilibraton of the agroecosystem.

Sugarcane

Introduction

Sugarcane is a crop that originated in the wet tropics of Melanesia, but has been most successfully grown in tropical wet-dry and sub-tropical climates (Barnes, 1974). It has been cultivated as a sweet reed for chewing in West Africa since its introduction there in about the 15th Century. It was probably introduced much earlier in East Africa. However, by the mid-1920s only two continental Africa countries produced significant amounts of sugarcane--Mozambique and South Africa. Mauritius and Reunion dominated African sugar production at that time. Between the mid-1920s and early 1970s sugar production in Africa grew nearly eight-fold, out-distanced only by South America (Barnes, 1974). The drive to produce sugar in Africa was spurred by WWII, colonial investment in developing cheaper sources of sugar, resolution of the problem of how to create higher yielding hybrid varieties of cane, multiple year cycles of high prices and inclusion of self-sufficiency in sugar producion as a national planning goal (Barnes, 1974; Purseglove, 1975). High prices for sugar in the early 1970s led to crash planning and production of sugar development. Overproduction, competition from sugar beet, sugar from protected markets and development of non-sugar sweeteners has led some analysts to believe that sugar prices will exhibit a flat trend over the next decade or more (Singh, 1983). However, major new sugar projects have been designed and implemented in African nations to provide import substitution for rapidly growing sugar consumption (Nigeria, Ivory Coast), to obtain some foreign exchange from exports (Burkina Faso, Malawi, Kenya, Zimbabwe) and, in a few cases, to determine the economics of sugarcane as a basis for ethanol production as a fuel substitute (Zimbabwe).

Both the history and the agronomy of sugarcane development are focused on large-scale production. Production has to be closely linked to processing operations to avoid post-harvest losses of sucrose conversion. The processing operations are generally more efficient at larger than smaller scale if white sugars are the desired output. Smallholder participation is usually limited to an outgrower role, providing cane to a mill which has a significant proportion of its capacity supplied by a nucleus estate or series of estates. Smallholders outside these schemes generally confine their production to old varieties. They are grown under conditions which produce low sugar concentrations and are used for chewing use or crude jaggery sugar (Brown, 1974).

Irrigated and Rainfed Production

Irrigation and/or drainage works are key features of many sugarcane plantations. The reason is that sugar yields and crop management tend to be highest when there is a dry or cool period to permit maturation--the slowing or stoppage of growth which permits accumulation of sucrose in the cane. Environments which have distinct dry periods may also have low reliabilty of rainfall at times when rapid growth of cane is desired.

Both irrigated and rainfed sugarcane production exists in Africa. In areas with high rainfall, well distributed over a several month period, sugarcane has been grown successfully without irrigation. In some lowland areas water control has revolved more around flood protection and drainge than water application. But, as shown in Table 34, rainfed production in marginal areas may result in a reduction in both yields and the lifespan of the perennial sugarcane plant relative to that grown under irrigation.

TABLE 34

CANE YIELDS AT LUABO ESTATE, MOZAMBIQUE
(In Tons per Acre)
1968

	Irrigated	Rainfed
Plant Cane	69.3	51.6
2nd Ratoon	36.2	16.8
3rd Ratoon	30.9	12.4
4th Ratoon	29.9	n/a

Source: Barnes, 1974, Table 4.

These results are from an industrial plantation located on an alluvial floodplain in Mozambique. Sprinkler irrigation was used. Across both classes cane yields drop significantly from the first harvest to the third. Rainfed yields are 75 percent of irrigated yields at first harvest, then drop to 40 to 45 percent in the third and fourth harvests. By the fourth ratoon crop, rainfed plantings had to be abandoned. However, a complex of factors including drought tolerance of the varieties tested may have accentuated the difference between rainfed and irrigated production.

A more recent study of production from irrigated and rainfed sugarcane in another wet-dry environment in Ivory Coast indicates that varietal improvement had probably reduced the gap between irrigated and rainfed production, perhaps bringing rainfed production within range of economic competitiveness with irrigated production. In a fifteen-year study of the productivity of rainfed production under varying fertilizer regimes, researchers at Ferkessedougou demonstrated that for their rainfall regime and soils rainfed cultivation could provide about 75 percent of the extractable sugar and about 70 percent of total cane yields of the same variety grown under optimum irrigation conditions (Claus, 1982).

In contrast to the earlier example from Mozambique, rainfed crops maintained their yield position relative to irrigated cane across ratoon crops. The sites were carefully selected. Soils had a minimum potentially available soil water reserve of 120 to 150 mm either naturally or through ripping, and seed beds were well prepared. Great care was taken in selection of stem cuttings and growing practices were intensive. Still, Claus (1982) estimated that about 60 t/ha of cane, or 6 t/ha of extractable sugar, could be obtained under industrial or improved smallholder production in this environment, which averaged 1,300 mm of rainfall per year. Rainfall analysis showed that production would be fairly stable over time. Once in five years a 5 percent variation from the average could be expected. Once in ten years a 13 percent variation could occur.

It should be noted that the above results were obtained with intensive land preparation and unusual efforts to conserve soil moisture. The leaves and trash of the cane crop was manually stripped and used as a soil mulch. Cane fields in the Ivory Coast are usually fired before harvest to reduce manual labor requirements. The mulch contributed to higher soil moisture status and reduced weeding. Its net effect on labor use and cost compared to firing and manual harvesting, or firing and mechanical harvesting, was not evaluated. The dried mulch also presented a wildfire hazard for the ratoon crops. Standard Ivoirian practice in irrigated production is to rake trash to clear irrigation furrows before they are reshaped. Under rainfed production the fire hazard to the sprouting ratoon crop is fairly high until the rainy season begins.

Claus (1982) concluded that there was good potential for both industrial and village expansion into rainfed sugarcane production in northern Ivory Coast. He cited the lower cost in capital outlays; the shorter maturity period of the cane under rainfed conditions, which would improve cane flow to mills; and rainfed cane's generally higher sugar concentrations with closely monitored fertilizer practice; as factors which made rainfed production an attractive adjunct to irrigation. The proviso was that about a third to a half of production should be irrigated to dampen interannual production variations. Production in wetter zones of the country would permit some relaxation of the tight technical control required to maintain high rainfed yields in drier zones.

In Zaire there is a long history of supplemental irrigation of sugarcane (Drachoussof, 1959; Mohrmann, 1958). Both furrow and sprinkler irrigation is practiced. Rainfed cultivation is possible in the major sugarcane growing areas in Bas Zaire, but the distinct, strong dry season of three months, which provides a good maturation period, also interrupts the planting cycle. Supplemental irrigation permits planting during the dry season. Rainfall distribution is bimodal in Zaire, so the supplemental irrigation also permits high growth rates to be maintained during the January-February period when moisture stress in rainfed plantings can be expected. Equally important is the effect of supplemental irrigation on the scheduling of both labor needs and machinery use. Labor peaks are reduced and machinery use more flexible when cane harvesting and planting can be stretched out over an additional three months when compared to rainfed production.

In the Kwilu Ngongo area of Zaire both irrigated and rainfed production takes place. Rainfed cane yields average about 75 t/ha for the first cutting and from 30 to 40 t/ha for succeeding ratoons. Under irrigated conditions from 180 to 200 t/ha can be obtained from a first crop grown over an 18-month period, with 12-month ratoon crops averaging about 80 t/ha (Vandenput, 1981). Harvesting is done by hand to permit maximum recovery of mature stems. While this practice maximizes sugar recovery, it is unclear whether the practice is economically optimum.

In the Kivu region in eastern Zaire, sugarcane is grown at 980 meters in the relatively fertile Ruzizi Valley with furrow irrigation. Rainfall is lower than in the Zaire basin and at the margin for rainfed sugarcane production--about 1,200 mm per year. Varietal trials with Indonesian and Indian introductions showed potential yields on the order to 140 to 180 t/ha of cane. Ratoon crops dropped to about 100 t/ha. The growing cycle was based on a 13-month first crop followed by two ratoon crops of 12 months duration (INEAC, 1959). High yields can be ascribed to intensive management, supplemental irrigation, fertile soil and sunnier conditions than in the lowland areas of Zaire. Full-scale production yields were reduced to about 60 percent of trial yields.

Under conditions of adequate soil moisture, soil fertility and high insolation, the rate of growth to maturity can be accelerated. In Africa these areas are in arid or semiarid zones. At Tillaberry in Niger total water applications of 2,090 mm over a ten-month growing period yielded 90 to 120 t/ha of sugarcane for the first harvest (Valet and Marcesse, 1980).

It can be seen from the preceding examples that site and crop management practice can be combined in many ways to maximize sugar production. The crop can be grown for one year, two years or 18 months before harvesting. Ratoon crops can be varied in number and duration. Mechanization can be nearly total or selectively employed. The combinations and permutations of agronomic management are many. Water supply plays a key role in manipulating growth rates and maturation periods within certain limits set by environmment and variety.

Varietal Decline and Improvement

Sugarcane is subject to a phenomenon known as varietal decline. In some crops the failure of a variety can be attributed to a single disease organism that causes an epidemic or mutation of a disease to a new race for which a variety has no resistance. Long experience with sugarcane has shown that varieties tend to decline in their yielding ability over a period of two decades or so to the point that they cannot be grown economically. Since the breeding and testing cycle for new varieties is seven to ten years, cane production strategies have been oriented to continuous testing of new introductions and local selections, along with the cultivation of several varieties on one plantation.

Varieties differ in their susceptibility to decline in the same environment and rates of decline for the same variety often differ across growing environments. Genetic makeup; bacterial, fungal and viral diseases; insect pests, nematodes; and environmental stresses have all been implicated in varietal decline (Barnes, 1974). The problem has been reduced mainly by introduction of interspecific hybrids of sugarcane with vigorous growth habit, disease and pest resistance and desired sugar yield characteristics. Also important has been the establishment of quarantine procedures for introductions to avoid disease and pest carryover into new environments. Across all varieties and environments, standardization of hot water treatment to control Ratoon Stunt Disease has proven to be extremely beneficial. Improved cultural practices and sanitation in seed piece preparation has reduced disease carryover into succeeding crops on the same plantation. Combination of varietal improvement to incorporate stable resistance to diseases and insect pests and improved quarantine and cultural practices led to large increases in recovered sugar over multiple ratoon crops (Barnes, 1974).

As breeding methods for disease and pest resistance have been improved and cultural practices have been fine-tuned to economically optimize sugar yields, attention has turned increasingly toward examination of varietal differences in response to environmental and management factors. Nickel (1976) reviews work in Hawaii that shows the great varietal variability that exists in response to solar radiation, temperature, drought tolerance, wind stress, salinity, flooding and fertilizer. The implication of the work is that improvements in matching varieties to local growing conditions will increase managerial control over crop yields and production costs. As has been shown by studies in West Africa, there are significant differences in variety to different environmental conditions (Claus, 1982). Optimization studies before large-scale plantings and regular crop monitoring are necessary to develop cost-effective management of the sugarcane stands.

Pest and Weed Management

Termites, root grubs, stem borers and nematodes are the four major pests of sugarcane in Africa. Termites are especially important pests of newly planted seed pieces or of standing cane during prolonged or intense dry seasons. Root grubs and nematodes affect plantings of all ages under many different moisture regimes. Stem borer has been increasing in importance as a cane pest in West Africa since 1965, when major new irrigated cane projects (Banfora in Burkina Faso, Ferkessedougou in Ivory Coast, Seribala and Dougabougou in Mali) were constructed. Substantial varietal resistance to root grubs and nematodes has been developed. Termites are controlled to a certain extent by dieldrin treatments of seed pieces, broadcast applications of dieldrin and endrin and by flood irrigation practices (Barnes, 1974). Some stem borer resistance has been incorporated in major cane varieties, but the review of West African experience by Betbeder-Matibet (1981) shows the complex interaction of control practices for termites and root grubs with those for stem borers.

Stem borers are a particular problem in new cane stands and in some ratoon crops. One of them, Eldana saccharina, can infest up to 30 percent of new plantings on cane. The cause seems to be the suppression of a controlling fauna of insects and ants by field-wide applications of insecticides and flood irrigation. Carryover from one crop to the following ratoon or to an adjacent field is caused by failure to eliminate the basal stem reservoirs of egg masses and larvae of the borer. Borer incidence declines as stems become less succulent and predator fauna recovers. Cultural practice improvements were recommended as the most practical control methods pending research on biological and chemical techniques. Cultural practices included:

- Selection of uninfected seed pieces;

- Selection of seed pieces from nine- to ten-month-old cane;

- Dieldrin treatment of seed pieces only to protect against termite attack while reducing destruction of beneficial insects;

- Sprinkler irrigation for crop establishment--emerging borer larvae are drowned and predator fauna are not drowned by flood irrigation;

- Harvest the first crop at a maximum age of 12 to 13 months and harvest to ground level--the timing favors suicidal emergence of the moths at an unfavorable time of the year and field sanitation reduced potential egg lying habitat; and

- Destruction of stools of the previous cane stand after the last ratoon crop.

Post harvest insecticide treatment showed greater stem borer attack than untreated checks (Betbeder-Matibet, 1981).

Deuse and Bassereau (1980) review the status of weed control in irrigated sugarcane projects covering 50,000 hectares in francophone West Africa. About 75 percent of the surface area is treated with herbicides. There is generally not a problem with weed control during the first crop, which undergoes several tillage operations up to full cover. Then succeeding ratoon crops usually develop a strong weed challenge, especially after field firing. Herbicides tend to shift the weed population to tolerant species, which require different herbicides for control or are highly resistant to many herbicides (e.g., Imperata cylindrica and various Cyperaceae). Since the major problem species vary extensively within a project, Deuse and Bassereau call for vegetation surveys before field planting, examination of non-herbicide control measures and studies on optimization of herbicide applications. Depending on field irrigation and drainage ditch layout, there may be economic and operational constraints to mechanical cultivation of ratoon crops (Barnes, 1974). At early stages of the ratoon crop, sprinkler irrigation could permit greater flexibility in terms of mechanical cultivation. A combination of sprinkler irrigation and trash mulching usually freely trashing varieties--varieties that drop their leaves easily--would provide good weed control, but would be too costly where labor is expensive.

The Large-Scale Nature of Sugarcane Production and Smallholder Isolation From Technological Advances

Because sugarcane is an industrial crop, economic optimization of production, harvesting and milling processes is dominant in technology identification and adoption. As the sugar market is international in scope and volatile in nature, periodic adjustments have to be made in all levels of production and processing activities to maintain market positions. At the same time, sugarcane is a perennial crop--or nearly so. It requires fairly long lead times to develop new varieties and production practices and move them into the production sector. These pressures have produced a close association between research and production. Essentially, all large schemes have research and development programs and are in fairly close communication with sugar research workers around the world. Thus, although lead times are long in varietal and technology development, the industry as a whole is poised to incorporate new developments. In many cases the industrial plantations are the sites of research on a large plot of field scale. Once results are interpreted, the improved variety or technique is quickly adapted and integrated into plantation management.

Smallholders in Africa are generally outside the sugarcane research and development circles. Varieties, growing practices, input use, maturation techniques and harvest technologies lag a decade or more behind the main plantations. While Barnes (1974) asserts that smallholder production could be increased quite rapidly through use of improved varieties, better site selection, preparation of disease-free sets of high quality fertilization and modified harvesting practices, the intensity of organizational, extension and credit effort required could cost a good deal more than the increased crop would be worth. As far as is known, there are no programs in Africa which work on sugarcane improvement or sugarcane-based cropping systems for smallholder conditions.

Cotton

Africa produces about 1.2 million tons of lint cotton annually

(Vandenput, 1981). Sub-Saharan Africa produces about 700,000 tons of lint annually with fairly large year-to-year variations (Singh, 1983). The average yield in the sub-Saharan region is 570 kg/ha of seed cotton (190 kg/ha of lint), or about half of developing country yields (Singh, 1983). However, average yields in sub-Saharan Africa have been trending upwards at an annual rate of about 2.1 percent--higher than the worldwide trend, but significantly lower than the rate for developing countries in general (Singh, 1981).

The main reason for both low yields and high interannual variation is because the vast majority of cotton is grown under rainfed conditions. Sudan is the major exception. Its massive Gezira scheme and subsequently developed irrigation projects produce long staple cotton on about 325,000 hectares, with an additional 50,000 hectares of rainfed medium staple production. Sudan produces about a third of the region's cotton (Singh, 1983). Irrigated cotton is also produced in Mali, Kenya, Tanzania, Mozambique and Zimbabwe. Recessional cotton is grown in Chad and Madagascar.

Irrigated Cotton Yields

Long staple cotton yields on the Gezira scheme and on more recent projects in Sudan have been stagnant or declining for the past ten years (DAI and RTI, 1982; Benedict et al., 1982). Inadequate pest and weed management, drainage problems, poorly mechanized practices, lack of harvest labor and poor farmer management are factors at the micro level that account for declining yields. The Sudanese irrigated cotton producing areas are also a case study in the over-utilization of pesticides and the development of a tenacious pest complex. White fly damage and white fly transmission of viral diseases such as leaf curl are a major problem, although some resistance has been found in the Sakel varieties. However, resolution of these problems will remove only some of the important root causes of cotton production problems. Based on circumstantial evidence, other problems are macroeconomic dislocations in the Sudanese economy, scheme organization and management, a monopolistic and unresponsive cotton marketing organization whose prices present growers with disincentives for cotton production and allocation of all tenant water charges to the cotton crop (DAI and RTI, 1982).

Recent studies of historical long-term cotton yields in the United States suggest that yields tend to level out and decline despite steady improvements in genetic yield potential of new varieties. Meredith and Bridge (1984) showed that U.S. cotton yields were unchanged from 1866 through 1935, increased at the annual rate of 10.4 kg/ha from 1936 to 1960 and have declined at an annual rate of 0.92 kg/ha from 1961 through 1980. Throughout the period from 1910 through 1980, genetic yield gains were continuous. During the 1960s to the present, when cotton yields at the farm level were declining, average annual genetic yield improvement was seven kg/ha. Therefore, the natural and management environment for cotton production has declined since the early 1960s in the U.S. A large number of factors are probably involved. Lee (1984) points to difficulties in control of the bollworm (Heliothis) complex, the expansion of cotton production into low productivity environments and management practices by farmers which are aimed at economic optimization of production rather than maximization of yield. However, yield declines in high productivity irrigated environments such as California are important. Monocultural practices, pollution, herbicides, pesticides, integrated pest management, new pest appearance, new biotypes of pests, soil erosion, nutrient depletion, soil compaction, decrease in soil organic matter and many other factors and their interactions have been circumstantially linked to yield declines (Meredith and Bridge, 1984).

These studies suggest that irrigated cotton production problems in Sudan may not be remedied when the irrigation schemes are rehabilitated and reorganized. One little explored element in Gezira crop management has been the switch in 1975-76 from an eight-year fallow and fodder intensive rotation to a four-year cotton-wheat-peanut-fallow rotation. Shifting the cropping pattern to more frequent cotton production has probably intensified crop and water management problems. For example, the reduction of fallow periods may have reduced the soil depth to which cotton extracts water. Work on fine textured soils elsewhere has demonstrated the utility of two-or-more-year grass or fodder legume fallows on depth of water extraction by cotton (Longenecker and Erie, 1968). While the Gezira scheme has a large proportion of "self-plowing" soils or vertisols, rapid swelling of the soils after wetting and compaction over time has reduced root penetration in many areas of the scheme.

In new areas for cotton production, high yields may be obtained. Trial yields up to 4,000 kg/ha of seed cotton have been achieved in Chad, in the drained polders of the Bol Archipelago in the Lake Chad basin. In Madagascar, recessional production of cotton during the dry season produces yields between 3,000 and 4,000 kg/ha of seed cotton. In the same country, supplemental irrigation of cotton during the rainy season yields about 1,800 kg/ha (Parry, 1982). The yields from the recessional areas of interest because they parallel some of the results obtained from flood fallowing or from growing a crop of cotton following flooded paddy rice in the United States. Bell (1984) states that cotton following a paddy rice crop showed very substantial yield increases. Flooding alone reduces diseases but not to the extent of both flooding and paddy production. Except in Madagascar, a rice-cotton rotation is not generally practiced in Africa.

Pest Control

Irrigated and rainfed cotton production in Africa is constrained by insects, weeds, disease, fertility and soil moisture, in about that order. Cotton insect problems and their control are discussed in numerous reviews (USA and the World--Elliot, 1968; Kohl and Lewis, 1984; Tropics--Purseglove, 1968; Africa--Vandenput, 1981; Parry, 1982). In the technologically advanced countries the trend over the last decade has been toward integrated pest management strategies combining cultural practices, biological control and chemical control at the farm level; and in area-wide pest population control programs. Biological pest control opportunities in developing countries have been reviewed (Greathead and Waage, 1983). In Africa improved timing of chemical control, based on better knowledge of insect life cycles; more efficient pesticide application methods, such as ultra-low volume (ULV) spraying; and resistance breeding have been emphasized. Gillham (1972) reviews efforts to develop control methods for cotton insect pests in Malawi, Zambia and Zimbabwe. He traces a progression from reaction to catastrophic crop failure, which resulted in unsuccessful single insecticide control approaches, to progressive exploration of pest biology and response to pesticide treatment and the search for resistant varieties.

Currently, numerous projects in Africa, financed by IBRD and the European Development Fund, have been launched with strong components in improved insecticide and herbicide programs. In Sudan the larger international agrochemical firms hold contracts to provide pest monitoring and control services to the Gezira Board, Mechanized Farming Corporation and other major irrigated and mechanized rainfed schemes. While the need to upgrade insect pest control approaches in Africa is recognized, the lack of intensive research on the biology and population dynamics of pests and their predators, the management complexity and intensity of the IPM approach and the institutional interests of chemical firms are severe constraints to its introduction. The improved environment for pest proliferation in cotton under irrigated conditions, through longer periods of crop production, which include alternate hosts of pest species; the likelihood that longer growing cycles for cotton will be preferred by farmers, leading to greater buildup of diapausing bollworms; and increased sugar and other sap components in more succulent plants, make cotton pest control in irrigated conditioins a difficult problem (Rivnay, 1972).

Weed Control

A major problem in many rainfed and irrigated production areas is early weed challenge to the cotton crop. Chandler's (1984) review of weed control in cotton indicates that weed-free maintenance of stands for up to nine weeks was necessary to prevent yield reductions. Neglecting cotton weeding after six or nine weeks of weed-free maintenance led to 16 percent and 12 percent losses in yield. Hand weeding is still dominant in both irrigated and rainfed cotton areas in Africa. Thus, labor required to hand weed holdings would be high if farmers were to follow recommended practice. In many settings the need to carry out weeding operations on food or more remunerative cash crops leads to neglect of cotton parcels. It is not uncommon to find that the cotton planted away from access roads normally traveled by supervisory personnel is smothered in weeds, leaving spindly, etiolated plants that have lost 20 to 40 percent of their yield capacity.

Preplant tillage is most commonly used to control standing vegetation. Although paraquat and dalapon have been used in some cases, failure of farmers to carry out hand weedings after planting often eliminates any early advantages in stand establishment. More effective have been pre-emergence applications of alachlor, cyanazine, diuron, fluometuron, norflurazon, prometryn and trifluralin. Applied at planting under favorable conditions, they give cotton plants a head start on weeds. In systems where nitrogen is side-dressed after planting, the weed-free period may approach optimum conditions. The pre-emergence herbicide controls weed growth before germination and for a short period during stand establishment. Hoeing in a nitrogen fertilizer protects cotton for an additional period of time. Where animal traction is available or soils permit tractor passage, mechanical cultivation may be practiced, but is generally rare on irrigated perimeters. Post-emergence sprays are used, poor timing, poor application and costly application has led to ineffective weed control, as was the case in the Rahad Project in Sudan (Benedict et al., 1982). As a rule, good land preparation, a pre-emergence herbicide or early mechanical or hand weeding, and a well-timed second and third hand or mechanical weeding will provide a reasonable level of control. No work on biological control of weeds in Africa was found.

Disease Control

Diseases particularly prevalent in irrigated production include seed and seedling diseases such as *Fusarium spp.*, *Alternaria spp.*, *Rhizoctonia solani*, *Sclerotium rolfsii* and *Pythium spp.* The seed-borne diseases in Africa are often favored by failure to delint and treat seed. Failure to delint also lengthens the period before seeds germinate, as lint delays imbibition of water by the seed. *Fusarium* wilt is the major wilt disease found in warm areas. *Macrophomina* root rot occurs as well (Bell, 1984). Most irrigated areas now use cultivars resistant to the black arm or bacterial blight organism *Xanthomonas campestris* var. *malvacearum*. Some rainfed areas with obsolete cultivars remain as reservoirs of this disease. Two viral diseases cause major damage annually in irrigated cotton in Africa. One is leaf curl transmitted by the Whitefly *Bemisia tabaci*. The second is blue disease transmitted by *Aphis gossypii*. Boll diseases affecting lint yield and quality are caused by *Diplodia*, *Nemantospora*, *Aspergillus*, *Fusarium* and *Coletotrichum spp.* (Bell, 1984; Vandenput, 1981). Many of the boll diseases are the result of boll injury by a variety of insects which provide points of entry for the pathogens. Varieties with resistance to bacterial blight, *Fusarium* wilt, and blue disease have entered into production. Selection of seed for high vigor, careful control of nitrogen fertilization to avoid aggravation of wilt severity, potassium fertilization to avoid potassium deficiencies favoring wilts, adequate irrigation, rotations and clean tillage have all been recommended as ways to control disease incidence (Bell, 1984). Chemical control of cotton disease is seldom economic. Biological control and solarization to destroy soil pathogens have yet to prove their economic viability or practicality for cotton in the developed or developing world.

Fertility Management

Hagin and Tucker (1982) review the fertilization of irrigated cotton produced under arid conditions. Particular attention is paid to nitrogen nutrition. The close linkage of nitrogen nutrition to irrigation management is emphasized. They find that:

- Nitrogen should be at an adequate level from the beginning of growth;
- An ample supply is needed near bloom;
- Best yields and quality are obtained if soil nitrogen is depleted after maturity; and
- The deep roots of cotton enable the plant to take up leached nitrates from the lower soil horizons.

While the variability of soils and their management needs means that nitrogen fertilization practices vary considerably, a complete NPK fertilization generally is carried out. In many countries in Africa a "cotton fertilizer," or engrais coton, is used which includes sulphur and boron in the mix. Given the more pressing problems of insect, weed and disease control, fertilizer practice on irrigated cotton in Africa generally is based more on past experience, cost and convenience than on extensive adjustments following soil or petiole diagnosis.

Discussion of consumptive use and water requirements of cotton produced on irrigation schemes in Africa is not particularly useful. Water consumption, when measured under controlled experimental conditions, falls within the 750 to 1,200 mm range cited by Bielorai (1983). A study in Niger showed consumptive use of 925 mm for a 131-day cotton variety yielding 2,130 kg/ha of seed cotton (Valet and Marcesse, 1980). Various authors indicate that the total water requirement for economic cotton production is a minimum of 450 to 660 mm of rainfall (Wilsie, 1968; Ilaco, 1982; Waddle, 1984). In Africa cotton is grown as a rainfed crop in areas with rainfall from 400 to about 1,500 mm.

Total water applications and method of application vary widely. Main system management tends to be the limiting factor in control of water application. Much reliance is placed on preplant flooding of basins or furrowed fields in Sudan, Mali, Niger and Chad. Subsequent irrigation scheduling is more a function of water availability than of attempts to optimize applications in terms of cotton growth stages.

CHAPTER SIX

SOCIOECONOMIC ISSUES

Because the creation of a water delivery system usually precedes the organization of farmers within any of the larger irrigation schemes, and because of a mutual lack of understanding of each other's disciplines, neither engineers nor social scientists have a clear idea how the technical and social systems interface within an ongoing irrigation system. Here the word system is central, since it implies that the structure of activities encompasses both natural and human subcomponents. The points where some coordination is necessary between the technical and socioeconomic aspects of irrigation include:

- How land and water rights are acquired and allocated;
- The physical design of a system in relation to existing land use;
- Any activity where farmers participate in the planning and construction of the system;
- The timing of water releases, and thus of farmers' labor input;
- Constraints on irrigation generated by farmers' preferences and other enterprises;
- Arrangements for any common services provided by the scheme, e.g., puddling of fields or transport;
- Systems for conflict resolution linked to water management;
- Any maintenance contributed by farmers;
- Organization of crop marketing if done jointly;
- Repayment by farmers of scheme costs and operating charges;
- Backward and forward linkages generated by irrigation on the larger economic and social system; and
- Increased health costs associated with irrigation.

It can be seen that these points of interface between the technical aspects and farmers' well-being cross-cut the agronomic, economic and social domains. The complexity is such that neither the technical nor the socioeconomic aspects can take automatic priority. For purposes of discussion, we deal in this chapter with the main farm level issues before returning in Chapter Eight to the larger issue of scheme and project-level economics.

Two observations can serve to introduce the topics highlighted in this chapter. First, irrigation technologies differ greatly in what is expected from farmers and in the demands they impose on the economic system. Surface irrigation based on canals and flood basins will require far more modification of the physical environment than, say, a pressurized system employing portable piping and overhead sprinklers. Capable field engineers can usually provide water for crops in several ways, some requiring major changes in farmers' lives, but others not (Keller, 1985).

There is no intrinsic reason why social factors cannot be considered when choosing an irrigation technology--though, admittedly, this is unlikely to happen if the social dimension is left until after physical works are already constructed. Negative social costs associated with given irrigation technologies often may not emerge into full view for a number of years, long after designers have moved on to other projects. Thus, we argue it is especially important for water management specialists to understand the social implications of technology choice from the very beginning of project design. Otherwise, the sequential nature of the project cycle has the effect of leaving social considerations until the end, when it is too late to modify the major decisions involved in choosing and installing the technology.

Second, the popularity of small-scale pump irrigation systems (responsible for their rapid spread throughout much of the Sahel) is probably because such systems make minimal demands on the farm household. A farmer buying a small pump to replace the traditional shaduf retains almost complete control over its use, subject only to fuel availability and access to repairs. The process of technology adoption is here much like that found on an American farm, except that the scale is an order of magnitude smaller. When these independent farmers buy their own fuel, they are in effect paying a "water users charge."

At the other extreme, a tenant who takes up an irrigation plot within one of Africa's larger schemes must usually accept many controls. Depending upon the system, schemes have attempted to control farmers' residence, inheritance, use of water, choice of crops, planting of trees, keeping of livestock, marketing of crops, and even (in some instances) permission to use modern transport. It is little wonder that African irrigators sometimes view themselves as government workers, carrying out elaborate instructions for the privilege of becoming sharecroppers.

Several features of indigenous African socioeconomic organization complicate farmers' likely response to the adoption of modern irrigation technologies. First, there is the constraint imposed by the tiny size, mixed cropping and non-contiguous pattern of many farmers' fields. Physically this makes the design of a common system difficult; economically it means farmers have insufficient cash flow to support major capital investments on their land. Second, over much of Africa a woman and her children constitute the basic food producing unit. Addition of an irrigated plot as a speculative investment by a husband does not necessarily guarantee the family labor it requires (here note that both rice and cotton are very labor-intensive), nor will it automatically benefit other members of the household. Third, the small-scale, incidental nature of traditional irrigation caused it to be viewed as a hedge against famine, but not as a person's primary farm investment. Fourth, until now most yield increases in Africa have occurred because of expansion into new lands rather than intensification within existing production. Specialized, mono-crop farming of the kind in traditional Asian "wet rice" communities has been rare in the African setting. And fifth, within the drier lands where irrigation is often proposed, it competes with livestock and trading enterprises for a farmer's capital. Depending on how it is planned, irrigation can hinder or support the keeping of livestock (FAO, 1983). Let us examine some of these aspects in greater detail, since they explain in part the disappointing performance of irrigation technologies in the continent.

Farmers' Production Strategies

Most American irrigation specialists are accustomed to a situation characterized by demand-led technology diffusion. The choice of application technology is left to the operator, whose holdings are often extensive and whose farm operations are largely mechanized. A beginning insight for understanding how African irrigation differs is to realize that the technology is not spreading because of farmers' demand. Indeed, African farmers' own preferences differ diametrically from the premises underlying adoption of irrigation. The differences can be represented schematically as follows:

Farmers' Own Strategies	Irrigation as a Production Strategy
Subsistence orientation	Commercial orientation
Replant own seed	Purchase seed
Staggered planting of multi-crops	Uniform planting of mono-crop
Yield increase by expansion	Yield increase by intensification
Minimize use of purchased inputs	Maximize yields by high input use
Invest profits in animals	Invest profits in equipment
Exploit different environments	Concentrate on one environment
Diversify to reduce risks	Specialize to reduce risks

Of course, not all farmers adopt the strategies listed above, just as irrigation need not involve high input use or the exclusion of livestock enterprises (though, in fact, both features are part of the usual pattern for "official" irrigation schemes).

Farmers' own preferences should not be viewed as "conservatism," an irrational holdover from out-moded ways of farming. There are a number of field studies of individual farming systems which show that traditional strategies generally give far higher returns to hours of labor input, usually by a factor of three or more in comparison to recommended "modern" technical packages (Alverson, 1984; Gathee, 1982; Glaeser, 1984). Alverson's data constrasting traditional and modern farming returns in Botswana (reproduced in Table 35) could be duplicated from many other dryland systems on the continent. What these show is basically that under conditions of high risk (either of moisture deficits, insect attack, price uncertainties or poor institutional support from input suppliers), it simply does not pay to specialize in enterprises which require a high level of purchased inputs. Ironically, this restriction is especially applicable to irrigation under the usual circumstances of unreliable water delivery and unpredictable input supply. For example, farmers observed near Janale on the lower Shebelli River in Somalia (in mid-1964 at a time of severe drought) were using basically rainfed farming strategies within their irrigated plots. On close inquiry, it turned out that seed germination rates were very low and farmers could not obtain fuel to run diesel pumpsets, even though their crops were wilting in the field within sight of the Shebelli River.

The above background helps to explain the unexpected finding that generally in Africa irrigation appears to be a sideline rather than the main enterprise for most farmers so engaged. Why this should be so is clearer if we visualize the typical, gently rolling topography found so widely on the continent. In addition to "red soil" field crops (once millet and sorghum, now maize), most households will also plant some "valley bottom" crops like sweet potatoes, yams, and rice in the depressional "black soil" areas. With high but variable risks affecting all peasant farming enterprises, an astute strategy for the individual household is to spread its commitments widely across different types of enterprises. Field crops (almost always non-irrigated) will be supplemented by goats, indigenous legumes, some fruit and the semi-irrigated valley "garden" plots. Farmers accustomed to this strategy will be willing to apply for rice plots within larger schemes, but may regard these commitments as a hedge against disaster in their other farming enterprises. Ironically, the one category of farmers who must rely on irrigation--landless immigrants recruited by the scheme agency itself--are the very ones subjected to bureaucratic controls which make their situation precarious.

Calendar Interfacing

Until a farming system is fully mechanized, a farm operator and labor force must be present for most of each season (with the one exception in Africa being the highly organized sugar schemes where the outgrowers' role is reduced to holding a plot right and repaying production costs at the season's end). Thus, scheduling emerges as just as significant an aspect for farmers as it is for the water delivery organization. Field irrigation requires a synchronization of water delivery, crop activities, and farm household activities. Within each of these three spheres certain components are in turn linked outwards to other periodic or episodic phenomena: fluctuations in water supply within the main system, rainfall, availability of inputs like seed or fertilizer, adequacy of the labor supply, transport and storage of the crop and the routine maintenance activities of the farm household. Obviously, the irrigation operator is still also a householder, with separate obligations to family members, kinfolk and neighbors. The term

TABLE 35

COMPARATIVE RETURNS TO 'MODERN' VERSUS 'TRADITIONAL' FARMING IN BOTSWANA

Per Hectare Costs (pula)	Ngwakgetse IFPP[a] Scheme	Bangwakgetse Traditional System
Capital depreciation (10%)	7.50	2.50
Hired labor	5.97	2.48
Fertilizer	25.75	0.00
Total:	39.22	4.98
Yield per half hectare (kg)		
Sorghum	261	142
Maize	412	137
Revenue per hectare (pula):	51.45	21.57
Gross margins per hectare: (Total costs deducted from total revenue)	12.23	16.59
Total labor-time required (hr):	199	83
Cash return to labor/hr	.06	.20

[a]Integrated Farming Pilot Project at Pelotsheltha.

Source: Hoyt Alverson, 1984, "The Wisdom of Tradition in the Development of Dryland Farming: Botswana," Human Organization, Vol. 43, No. 1, p. 5.

"calendar interfacing" is meant, then, to highlight the necessary synchronization of schedules which must occur across these separate domains of the total system.

A moment's reflection indicates that in each domain certain activities are highly time-bound and others are not. Over the whole season there will be some dates and events which occur irrespective of other activities, some which have an element of flexibility (i.e., can be shifted backward or forward by a few days), and still others that are fully discretionary (e.g., when to weed canals). One cannot assume events in any one domain will take automatic precedence over those in another domain. Furthermore, while some key events can be scheduled in advance, others cannot (e.g., the start of the rains). A prominent feature of farming in Africa is simply that for farmers and irrigation agencies alike, the control that can be exercised over the timing of key events and activities is substantially less than in a developed country. With higher levels of uncertainty being experienced in each major domain of activity, the necessary synchronization across domains becomes extremely difficult to achieve.

This unpredictability occurs partly because in Africa many river systems are not yet anywhere nearly under controlled flow; farm operations are much less mechanized (and the mechanical components have proven quite unreliable); and the numbers of smallholders whose activities must be synchronized are large. But it is also a function of high levels of unreliability in the economic and administrative support system, far beyond what one sees in a developed nation. Illustrative of these difficulties are the World Bank's "partial control" polder irrigation schemes in the Sahel, whose predicted output has not occurred because of extremely low river levels and the high uncertainty of the arrival of the rainfall needed to start off the floating rice crop (Brandolo, 1985).

With this background, let us briefly review some of the main "calendar interfacing" problems in African irrigation. One area of obvious disjuncture throughout the continent arises when smaller rivers rapidly dry up. For any run-of-the-river irrigation, supply problems emerge just when plants most need water. Another common discordance is that because of either a cloudy-cool season at mid-year (in eastern Africa) or the occurrence of drying winds (in the Sahel), the irrigated and rainfed cropping cycles must overlap. A third problem derives from the absence of cattle in the farming system at times when they might be used for animal traction, and their poor physiological state if they are present.

There are equally significant calendrical blockages in the sociological and administrative realms. Two stand out as being of special significance: financial liquidity over the season (what economists term fungibility); and interposition of major ritual occasions within the family's social calendar.

With regard to cash flow, we have noted several times in this report that the nature of irrigation is such that often farmers and irrigation agencies require continuing cash expenditure over the season. For farmers, the need arises because irrigation is input intensive and the inputs must be purchased; also, at peak periods outside laborers must be paid. As a rule, banking services are poor in the more remote areas of Africa. Farmers have money to spend only at the times of the year when they have been paid for crops sold, typically for only a short time and perhaps only on two or three occasions in the year. The main exception is farmers who own livestock which they can sell. The weak institutionalization of credit mechanisms leaves farmers unable to meet pressing cash demands from mid-season onward, just when fuel may be most needed to keep irrigation pumps operating.

Exactly the same dilemma faces the local water user association (if such an organization exists). Dan Jenkins (personal communication) tells of seeing the consternation of a USAID auditor upon learning that operational funds for Mali's Action Blé-Diré Project had been "invested" in livestock by the village leader entrusted to hold the money. However, we must see this from the participants' standpoint. In the villages being served by the irrigation pumps there were neither banks nor any secure way of holding ready cash to pay for fuel deliveries and mechanical services. The ownership of livestock is a matter of public knowledge at the village level, and hence, the conversion of the project's operating funds into livestock was probably the safest thing the village elders could do under their immediate circumstances.

At the level of the irrigation agency, access to banking services will not be a problem, but the organization's, donor's and government's financial year is. Throughout ex-British Africa the general rule is that public agencies must close their books before the end of the financial year, and--if they are under the Ministry of Agriculture--perhaps even return all revenues to the treasury while awaiting arrival of the next year's funding. These two events, the shutting off of expenditure for six weeks at the end of the financial year and waiting for the release of fresh funding, are very commonly encountered in African administration. This issue is further complicated if the irrigation agency must also accommodate its activities to a donor's financial year. Any experienced administrator in the local system can predict those times of the year when payments cannot be made, but this restriction can nonetheless cause serious difficulties within project implementation.

In much the same way, farmers also experience times when field activities are called to a halt because of other, more pressing social obligations. If, as in most larger surface irrigation systems, cooperation between farmers is essential to operate the system, then the cost to be paid is that farmers must remain responsive to neighborhood opinion and to the fulfillment of their social obligations. In rural Africa the Islamic month of Ramadan will be one such occasion. Being under injunction to neither eat nor drink during daylight hours, a Muslim farmer at Ramadan will find irrigation tasks especially odious. The farm family may also exhaust its cash reserves because of the nightly feasts. Other occasions which can severely disrupt production schedules are, of course, births, marriages, and funerals. Traditionally, a death was often followed by an extended period of mourning among a person's close relatives, and even, in some circumstances, by disbanding of the household. Within "western" culture rituals connected with births, marriages, and deaths have become routinized and abbreviated. While such events pose no threat within an advanced economic system characterized by monthly salary payments, they tend to be enormously upsetting within semi-subsistence agriculture where even a brief withdrawal of the labor force can have dramatic production consequences. Also, the rates of mortality and marital instability are often high in an African context.

In terms of the impact on the cropping activities, untimely pregnancy or illness in the family can be quite significant (though invisible to scheme managers). Women play such a large role in African subsistence production--a topic addressed below--that when for any reason they must withdraw from fieldwork, production suffers immediately. A powerful, though indirect, cost of irrigation is the time women must spend tending ill family members; in a survey on Kenya's Mwea Scheme in the late 1960s we found that 54 out of 99 households claimed to have at least one member of the household who was usually sick (Hanger and Moris, 1973). The dependency on a wife's labor input has increased in recent years as older children are withdrawn from the household to attend school.

The significant planning question is how calendar interfacing can be achieved within operational irrigation systems. Where one is looking at a fully-evolved system (such as Madagascar's Asian-style terrace irrigation), the necessary accommodations between domains will have been incorporated into the production systems over several generations. "Customary" practices will usually exist which either resolve or minimize common scheduling conflicts. However, this degree of institutionalization has not yet been reached in Africa's medium- and large-scale systems, where the technology is a recent introduction.

The second possibility is what we find in America or in Australia, where a large-scale operator makes timing decisions individually. Cross-domain implications are automatically (though informally) weighed because the individual is at the same time water controller, farm manager, and household head. Probably the person's previous experience is a critical consideration. This structural solution is seen in Africa at only two extremes: within very small, pump operated systems owned by one farmer; or among the immigrant, large-scale producers of Kenya and Zimbabwe.

The third solution is to install bureaucratic and technical staff in charge of the water and agronomy domains. On the surface this may seem to resolve the need for systemic coordination. In fact, the people appointed as staff in either the water delivery organization or the extension program will frequently not come from an irrigation background, and may not be from the local area. The disparity in power and training is magnified if there are vast differences in scale between perimeter management and farming units. Staff will not understand farmers' needs, and farmers will have little opportunity to express their own priorities. These stresses are likely to result in frequent breakdowns of activity coordination, ill-considered technical decisions and alienation of farmers.

The Labor Issue

One area where farmers' preferences and irrigation project assumptions frequently diverge is in regard to the labor input required by irrigation. We have noted above that involvement with irrigated production usually requires major changes in how the farm labor force is employed: differences in the timing of major operations; the hours when tasks are done; and increases in the total labor input. Nevertheless, the possibility that labor constraints are a major factor limiting output was in the past ignored. It was argued that traditional farming gives low yields, and farmers were thought to have few alternatives for the use of family labor. In addition, there was sometimes an implicit notion that by resorting to irrigation farmers could extend the season when major operations were being performed, making the new technology complementary rather than competitive with existing production. Provided the irrigated crop was efficiently produced, it was assumed that family labor would be forthcoming. In project appraisal documents, it was commonplace to treat labor as an unpriced, "free" input with zero opportunity costs.

That these assumptions are all erroneous should have been apparent long before now. Almost everywhere in tropical Africa (except perhaps in respect of certain root crops), there are very sharp seasonal bottlenecks when household labor becomes the limiting factor strongly constraining eventual yields. The first bottleneck occurs in land preparation, which often occurs at the hottest time of the year when both humans and animals suffer from inadequate nutrition. The second comes when crops must be weeded, since farmers can easily plant more land than their household labor force can keep clear of weeds. The third (often overlooked) bottleneck can occur when cereal crops must be guarded from birds, a task usually left in Africa to women and children, but nonetheless vital. And fourth, shortages of harvest labor sometimes occur. The particular periods of peak labor demand which farmers experience will obviously vary from season to season and farm to farm, depending upon each family's combination of enterprises.[1]

All of these labor bottlenecks derive in one way or another from the strongly seasonal nature of African rainfed cultivation. The parts of Africa where irrigation is often given priority tend to be those subject to a very long dry season of perhaps five or six months at a stretch. This means that all manual farming operations are concentrated in the relatively short period when moisture is surplus to potential evaporation. Since traditional varieties (of sorghum, millet and rice) were often of a relatively long duration, farmers are left in a quandry. In most cases, their crops will give higher returns if planted early in

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[1]Only a few sources deal adequately with the labor input. An especially useful discussion is contained in Keller et al. (1982:65-71), which can be supplemented by general data on labor inputs into northern Nigerian farming, contained in Norman et al. (1982:93-129). Other references include Arnould (1986), Cleave (1974), Clark (1975), Hanger and Moris (1973) and Wallace (1981).

the season. And yet the soil (particularly in the clayey, depressional areas) is difficult to work until wetted, and then everything must be done at once. The competition for labor at planting and weeding becomes severe, necessitating that each household find strategies for evening out the labor demands arising from a range of agricultural enterprises. Paradoxically, even though there are extended periods when the farm labor force has little to do, the availability of adequate labor still becomes a critical factor at the times of key labor demand. Thus, depending upon the season, the rural economy alternates between long periods when labor is surplus to crop needs and short periods when it is in sharp deficit.

There is abundant evidence, sociological and economic, to suggest that farmers have adjusted their mixtures and timing of crop operations to accommodate the extreme seasonality they experience. Strategies widely seen include the addition of high calorie root crops, which can be ignored at the peak periods; investment in smallstock, which children can care for when adults are fully occupied; developing valley-bottom (or "swamp") gardens where the growing period is extended; and the interplanting of crops crucial to household welfare.

Of the many examples which could be given, Dey's description of how Soninke women of Mauritania organize their labor must suffice:

> Before the start of the rains they plant short-duration rice seeds in holes in the lighter upland soils where weed infestation is not a serious problem. The rice germinates with the rains and gets established before weeding is necessary. The heavier clay soils in the depressions which flood during the rainy season are too hard to be touched until they have been softened by the first rains. Since weed growth is also rapid and strong with the rains, the women hoe in the first weeds and then broadcast their medium-to-long duration rice seeds which are harvested after the flood in the depressions has receded. In between these labor operations required by their rice, the women insert the work needed on their own or the household upland fields. (Dey, 1985:429-430)

The point is that in peasant farming, where people are reluctant to use purchased inputs, the main ingredient into the farming system other than land is labor. Calculations of production costs in Nigeria, for example, find that under traditional non-irrigated conditions, labor costs range from 65 to 93 percent of total production costs (with a median of 89 percent). Under improved, irrigated farming they decrease, but the median value is still 77 percent (PRC, 1982). In deriving farm budgets, then, how labor is priced will have a very large influence on the apparent profitability of the system. This effect is illustrated in the EEC's Wageningen study of eleven African irrigation projects, where the introduction into appraisal estimates of a shadow price for farm labor of half the prevailing market rate dramatically lowered the economic internal rates of return. In the case of the EIRR for Cameroon's SEMRY III project, which was estimated to be 14 percent at the appraisal stage, the inclusion of labor costs in the above manner brings the EIRR down to 8.3 percent (van Steekelenburg and Zijlstra, 1985).

The addition of irrigated farming changes the labor situation in a number of ways. The most obvious impact is to greatly increase the demand for labor, depending upon the choice of crop under irrigation and the overlap in field operations. Here, unfortunately, we encounter a wide range in estimates of crop labor need. For example, the labor input required to grow a hectare of rice under flood basin conditions in USAID's small-scale Bakel perimeters were estimated variously by successive consultants at 249, 322, and 645 man-days (Keller et al., 1982). The team reporting these figures derived their own best guesses, which were that labor inputs ranged between 400 and 1,000 person-days per hectare, with the distribution skewed toward the higher end.[1] Applying these rates under Bakel conditions (see Table 36), it was found that returns to labor for growing paddy only approach the local wage-rates being offered in Bakel under the best circumstances, i.e., yields of 5.0 t/ha, and no repayment of capital or variable costs (Keller et al., 1982).

The wages used in this comparison were derived from the one perimeter when government employees ("fonctionnaires") had given themselves plot rights, and so had to hire daily workers to carry out the irrigation tasks. The daily rate approximated 750 to 900 CFA for a six-hour day for men, but only 375 CFA for women (Keller et al., 1982). The authors suggest that the labor required on the rice perimeters "appears to exhaust the labor supply given such high labor flow rates." They also note substantial differences in work efficiency between men and women, adults and children, and experienced versus inexperienced workers. These differences are reflected in the local wage rates, but also have implications concerning a household's ability to meet crop needs. Land preparation is itself a function of soil type, with more energy required in preparing the heavy clay soils where rice (and cotton) are usually grown.

In the past, there has been a tendency to overestimate the amount of farm labor which a household can provide into its farming enterprises. A study of northern Nigerian farmers found that even in peak labor demand months, a male adult spent an average of only seventeen days working on the family farm, with seven days allocated to off-farm work (Norman et al., 1982). One reason is that at the peak periods households are in great need of cash:

> In savanna agriculture, little income is obtained from farming activities until after the bottleneck period is over. Cash and food resources tend to be low because most crops are harvested

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[1]The Wageningen study suggests that one hectare of irrigated rice grown without mechanization requires 150 to 220 man-days (1985:54). However, the Keller team mentions the view of one field technician that in some cases with unskilled labor 200 person-days were used on transplanting alone (1982:68). An informant in Chad reports 197 work-days per hectare (Weaver et al., 1985).

TABLE 36

RETURNS TO LABOR FROM IRRIGATED PADDY AT THE BAKEL PROJECT

Labor Inputs Per Hectare of Paddy (Person-Days)	Returns to Labor Per Person-Day for Various Production Circumstances		
	Worst (CFA)[a]	Normal (CFA)	Best (CFA)
	a. With No Repayment of Capital or Variable Costs[b]		
Low - 400	312	438	625
Medium - 750	177	250	357
High - 1,000	125	175	250
	b. With No Repayment of Capital[c]		
Low - 400	204	336	534
Medium - 750	109	179	285
High - 1,000	82	135	213
	c. With Full Repayment of Capital[d]		
Low - 400	0	254	473
Medium - 750	0	135	252
High - 1,000	0	102	189

[a]$1.00 US = 280 CFA in November 1981.

[b]Based on yields of 2.5, 3.5 and 5.0 t/ha of paddy at 50 CFA/Kg.

[c]Based on value of output less variable costs.

[d]Based on value of output less variable and capital costs.

Source: Keller, et al. (1982), p. 69.

between August and December. Therefore, the farming households... facing severe depletion of cash and food resources, are compelled to work in off-farm employment even though the work needs of their own farmers might be high. (Norman et al., 1982:120)

In practice, then, about 39 percent of the total days worked by adult Zaria males was spent on off-farm work. For the farm as a whole, the year-long average input per month was 150 man-hours, rising to 256 man-hours in the peak montn. The four busiest months of the farming year (which coincide with the irrigation season for rice) accounted for more than 50 percent of the total annual labor input (Norman et al., 1982). On average, male adults worked almost 1,200 hours per year, spread over 230 days (and indicating an average work-day of just over five hours if we include time spent walking to and from fields), but partly devoted to off-farm occupations (Norman et al., 1982:114). The household composition and its stage in the family development cycle have a large impact in determining whether adult males were available for farming tasks (we should note that in these Muslim communities men provide most farmwork, in contrast to other areas of Africa).

What about the prospects for rescheduling irrigation to avoid direct competition with farmers' rainfed crops? Here the difficulties are largely technical. First, on many African systems the source of water is also strongly seasonal. Unless a project is linked to a major river, an expensive dam, or a reliable aquifer, the time when water is surplus will coincide with the rainy season. Second, even when supply constraints are removed, it may be impractical to irrigate during the "haramattan" season when hot winds blow off the desert, or during the cool and cloudy weather which East Africa experiences at mid-year. These restrictions explain why irrigated production of at least the cereal crops tend to occur at the same time as rainfed cultivation, accentuating the competition for on-farm labor. It also explains the paradoxical finding that in farming systems where overall labor supplies seem surplus to local needs, nevertheless those doing irrigation often employ hired labor to overcome seasonal labor bottlenecks (Arnould, 1986).

The situation on Niger's small-scale perimeters is described by Arnould as follows:

> Problems of labor scheduling occur at all levels of production on the perimeters and there are conflicting overlaps between periods of critical labor demand... The harvest period for irrigated rice overlaps with the planting season for rainy-season millet; when millet fields require a first hoeing. Both operations are important to successful production, and in the case of rice transplanting, must be coordinated at the level of the irrigation unit to minimize charges for pumping water. These conflicts appear to cause difficulty more often for smaller than for larger households. (Arnould, 1986:9.)

They also make the achievement of adequate yields, and hence returns, critical for a household's continued involvement in irrigation.

Fresson's study of Senegal's small-scale projects warns that high mean yields at the perimeter level may gloss over severe problems faced by individual farmers. Within the Matam zone, average per hectare yields by perimeter ranged between 3 and 5.4 tons--an apparently good level of performance. However, when individual family returns were examined, in plots averaging 0.2ha each, crops of paddy rice obtained varied from 270 to 1,750kg, with a mean of 760kg (Freeson, 1978). Furthermore, these variations were caused not by differences in size of holdings, but by factors largely outside farmers' control. As Freeson notes:

> The wide variations of production and yield recorded... are due to the heterogenous nature of the soil within one and the same perimeter, or even individual plots of land, and to inadequate grading of the perimeters, with a direct impact on the flooding of plots. (Freeson, 1978:2)

Arnould (1986) records a similar situation when comparing irrigation performance in Niger (Table 37). As can be seen from these figures, the range between maximum and minimum incomes varies enormously, both among households and between schemes. Arnould's statement with regard to farmers in his Niger samples can be taken as being broadly true for most African irrigation projects:

> Irrigated production provides a complement to household cash earnings, and can be substantial in some cases, but it is costly income in terms of expenses incurred. In addition, irrigation is a risky venture, as the frequent cases of negative earning indicate. (Arnould, 1986:8)

All told, we agree with Wallace (1981) that the labor availability issue is central to the long-run success of African irrigation. Contrary to what most project appraisal documents assume, African farm households put a high premium on work-time, especially during the peak planting and weeding periods Their livelihood depends on how well they manage their work at these key seasons. Mass education for children, and the widespread involvement of men in off-farm occupations, already occur and will be accentuated in the future. Wage-labor rates are bound to rise. Until irrigation production can provide higher returns and greater security, it will remain the choice of a minority of farmers. We can predict that often laborers will be women, who have fewer options for earning cash, or poverty-stricken seasonal migrants from remote areas without a secure economic base. To succeed, families holding irrigation plots need to be large, having perhaps eight or more members (the current mean on several of the Sahelian perimeters). Even a half hectare of irrigated land may exceed the average family's labor resources. Sociological factors, such as the willingness of women to do fieldwork, how returns are shared within the household and the stage a family has reached in its developmental cycle, become very important. As modernization takes root; the array of alternatives influencing employment patterns is bound to become more diversified. This fact

TABLE 37

HOUSEHOLD INCOME IN NIGER SCHEMES

	Name of Perimeter			
INCOME BY SOURCE ($)	Namari Gongou	Toula	N'Dounga	Konni I
Irrigated Production	434	386	253	192
As % of total	46%	69%	51%	47%
Rainfed Production	517	173	241	218
As % of total	54%	31%	49%	53%
Mean total income ($ equivalent)	951	559	494	411
Range of incomes:				
Maximum ($)	1,536	1,260	875	836
Minimum ($)	-230	78	-278	-130

Source: Arnould (1986), pp. 7-8.

explained why large schemes which persist in growing lower value crops like cotton or rice are bound to experience labor shortages and tenant dissatisfaction. Furthermore, designers should not assume perimeters can extract "free" labor from farmers to do field leveling or the maintenance of field laterals.

Women in African Irrigation

Those familiar with farming in Asia or Latin America are unlikely at first to understand why the issue of women's rights within the farming system is so crucial in Africa.[1] In Asia and Latin America, despite many instances where marriages are quite unstable, most rural households show a division of effort much like our own "western" ideal of the "family farm." Full-time farmers are usually men, whose wives shoulder the household duties of food preparation and child care, which frees men to do the fieldwork. Sometimes women give key assistance to relieve labor bottlenecks--doing the transplanting of rice, for example, or helping at harvest--but in the main they do not control field activities unless the men of the household are away. This is also the case within the Islamic cultural pattern, extending as far south as the upper fringe of the Sahelian countries. A similar pattern of household task delegation is found in Madagascar, which in most aspects of social life is more Asian than African. Elsewhere in Africa, however, women have a much more central role in agricultural production, (see Table 38) and the integration of households as farming units is correspondingly weaker.

Lack of Household Integration

Several explanations might account for this striking difference in how household work and property relations are organized. Anthropologists would be quick to point out that within Africa's forest zone (e.g., among the Ashanti of Ghana) and within a large "matrilineal belt" of south-central Africa (southern Tanzania and parts of Malawi, Zambia and Zaire), indigenous social systems were matrilineal. Of course, this did not mean that women "ruled" their households (as Europeans sometimes assumed), but rather that a woman's brother and her natal family continued to hold property rights which were inherited by her children. The claims a woman could establish over land by virtue of marriage were accordingly quite weak. In these societies, a woman and her children constituted the basic family unit to which husbands were only tenuously attached. With root crops such as cassava, yams or bananas, which are quite productive relative to a modest labor input, it was quite feasible for men and women to maintain separate plots that did not constitute a jointly operated "farm."

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[1]Detailed sources on the role of women within African irrigation projects include: Bahemuka (1983); Dey (1980, 1981, 1984, 1985); Diarra (1982); Hanger and Moris (1973); Hochet (1975); Jackson (1984); Jones (1982, 1983); Moock (1986); and Umbadda and Abdul Jalil (1985).

TABLE 38

DIVISION OF LABOR IN TRADITIONAL AND IMPROVED RICE FARMING SYSTEMS[a]

			Traditional Rice Farming Systems					Improved Rice Farming Systems				
Cultivation Conditions	Country	Ethnic Group	Main Cultivator	Control of Household Crop	Control of Personal Crop	Rice Land Use Rights/ Ownership	Rice Land Inheritance	Main Cultivator	Control of Household Crop	Control of Personal Crop	Rice Land Use Rights/ Ownership	Rice Land Inheritance
Upland	Ivory Coast	Bete Gouro Senoufo	F F M	M+F M M	F F M	Compound Compound Compound	Compound Compound Compound	F F M+F	Not known M M	F F M	Compound Compound Compound	Compound Compound Compound
Inland Fresh Water Swamp	Ivory Coast	Senoufo	F	F	F	Compound	Compound	No planned developments for this type of rice which will probably be eliminated by current development projects to expand acreages and mechanize production.				
	Madagascar	All	M+F	M	n.a.	Mainly M	Sons	No significant development projects to date.				
	Gambia	Mandinka	F	F	F	Compound F	Compound Daughters	Development project started 1983 -- changes not yet known.				
	Upper Volta	Goin Turka Karaboro	F	F	F	F	Daughters	F	M	Reduced F	M	Sons
Mangrove Swamp	Gambia & Senegal (Casamance)	Mandinka	AS ABOVE					Only some technical developments so far -- no changes in socio-economic organization recorded.				
		Diola	M+F F	M/M+F F	M+F F	M/Compound F	Sons Daughters					
Irrigated Rice	Senegal & Mauritania	Toucouleur Soninke	Swamp Rice F	F	F	Mainly M/ Compound	Sons/ Compound	M+F	M	n.a.	M/ Compound	Sons/ Compound
	Zanzibar	Shirazi	Rainfed Rice - F	M	n.a	M+F	Sons/ Daughters	F	M	n.a	State/ M	State/ M
	Gambia	Mandinka	Fresh + Mangrove Swamp - F			AS ABOVE		M+F	M	Mainly M	M	Sons
	Upper Volta	Mossi	Swamp Rice F	F	F	Compound	Compound	M+F	M	n.a.	State/ M	State/ M

[a]Source: Dey (1985), "Women in African Rice Farming Systems." In: IRRI, Women in Rice Farming, p. 426.

Another set of factors are of historical origin. In the pre-colonial period many African societies encountered organized slave trading. This had an enormously disruptive impact on settled household life. In eastern Africa, while slaving was a late development, predatory raiding by cattle-keeping tribes like the Galla, Maasai and Ngoni had similar effects, accentuated by several devastating droughts and a rinderpest pandemic. Thus, the period just preceding colonial occupation was a time of great insecurity and much hardship.

Then, under colonial rule, the focus of economic opportunity shifted to certain enclave areas where either estates or mines were developed in easier reach of export markets. Both in West and in East Africa long distance labor migration by males became the statistically preponderant means for earning a cash income. Labor migration was often to another territory, requiring extended travel over huge distances (with men from Tanganyika traveling to the mines of South Africa and those from the Sahel to the West African coast). Women, therefore, were forced to become their family's main providers of food, grown on small plots while the men were far away earning a cash income. Most men eventually returned, but it was common knowledge that either the man or his wife might have meanwhile developed other attachments, contributing an added element of instability within the household. The exploitative nature of economic relationships, prior to and after colonization, perpetuated a situation characterized by weak family ties.

A third factor is the practice of polygamy. While nowhere were polygamous families the modal or most common form, polygamy was nonetheless the ideal within many traditional African societies. The mere anticipation of a polygamous union changes the nature of ties within the nuclear family and makes women more determined to maintain a separate economic base even in patrilineal settings where women tended to join their husband's families at first marriage.

Women and Food Production

For these overlapping reasons, African women tend to hold the major responsibility for growing the food crops upon which daily life depends. A women and her children constitute the basic household unit, to which men are attached for varying periods and by means of rather unstable marital unions. Farms operated by men do exist, but often incorporate separate plots for individuals within the family unit. Women commonly do most of the work on some plots, such as their food gardens, and some work on all plots under varying expectations of sharing in the yield. In some systems certain activities or crops are the responsibility of women and others mostly of children (e.g., bird-scaring from grain fields). Often, smallstock and poultry are under the woman's control--a substantial source of income, since these are sold much more readily than are cattle, and provide most of the meat a family consumes.

A valuable comparative study on the role of women in African rice farming has been completed by Dey (1984, 1985). She notes that generally when rice is grown as the household's food crop, it belongs to the household unit (whether grown by men or women) and is not supposed to be sold, except perhaps in small quantities to buy other cooking ingredients. However, when women grow rice as a personal crop:

> . . . they may dispose of it as they wish. Some is usually put on one side to feed guests or labor groups recruited to work on their rice fields the following season; some is also reserved for ceremonial obligations. Women sell the rest of their rice, either immediately after the harvest (when they generally get low prices) or they 'bank' it and sell small quantities bit by bit throughout the year as and when they need money. . . (Dey, 1985:430)

Indeed, the traditional varieties of rice which were domesticated in Africa appear to have been a woman's crop in a number of the farming systems where rice growing was important. As Dey emphasizes:

> One of the most striking points to emerge from all these case studies. . .is the enormous range of skills and knowledge that women have about rice cultivation ... which have essentially been passed on from mother to daughter. This includes very detailed knowledge of different soil types, toxicities and salinity conditions; water sources and fluctuating levels at different seasons and the problems posed by water control; an appreciation of the different characteristics of seeds ... agronomic practices, for example, to minimize weed growth and erosion and to maintain soil fertility; labor organization to reduce bottlenecks and to carry out operations at the optimum time to maximize returns. (Dey, 1985:429)

It seems logical that the amount of labor a women may contribute to her husband's irrigated crops will depend upon the rate of compensation she receives. Jones (1983) has tested this hypothesis with data from the SEMRY rice scheme in northern Cameroon. She notes that if husbands give their wives little or no money, "then women refuse to work on their husband's rice fields the following year" (1983:174). A simple optimizing model explains the difference in labor allocation between married and independent women, with independent women allocating more labor to rice. Jones argues that "at the margin, a family member would rather spend an additional unit of income fulfilling his or her own obligations than give it to other family members" (1983:176), a finding which invalidates the assumption usually made in appraisal documents that participating families constitute homogenous decision-making units.

It is difficult to substantiate these observations from further field data, since many of the earlier rural economic surveys assumed an integrated family holding, and obtained data mostly from heads of households. Table 39 gives data on plot ownership and husbandry from rural Senegal, which indicates clear differences between types of holdings and a generally disadvantageous situation for plots held by women individually. It should be noted that while such plots were the commonest type in the system, they were on average the smallest in size,

TABLE 39

ACCESS OF RURAL SENEGALESE WOMEN TO PLOTS

Status of Cultivator	No. Plots	Mean Plot Size (ha)	Total Area Under Groundnuts (ha)	(%)	Yield (kg/ha)	Ferti-lizer (kg/ha)
Compound head (carre)	50	1.54	77.07	37.9	1309	60
Household head	17	1.27	21.58	10.6	1273	39
Family labor (sourga)	78	0.74	57.91	28.5	1005	15
Seasonal labor (navetane)	15	0.89	13.37	6.6	1103	50
Women	86	0.39	33.47	16.4	847	19
TOTAL	246	0.83	203.40	100	1077	31

Source: Moussa Fall (1980). "Socio-Economic Aspects Involved in Introducing New Technology into the Senegalese Rural Milieu," In ICRISAT, Proceedings of the International Workshop on Socio-Economic Constraints to the Development of Semi-Arid Tropical Agriculture. Patancheru, India: ICRISAT.

obtained the lowest yields and utilized very little fertilizer. Jackson found much the same situation among Hausa farmers near Nigeria's Kano scheme, where pagan women were entirely excluded from farming the irrigation plots on their own. Where a few did obtain land through their husbands or sons, yields were very low:

> The reasons ... stem largely from the attitude of men to these plots; when allocating land the household head is likely to give women the least desirable land, i.e., land with poor soil or waterlogging problems ... It was found that only 1 of 47 women managed to get Fulani cattle corralled on her farm, only 17 percent obtained any manure or compound sweepings, only 6 percent used chemical fertilizers, and none belong to the Cooperative. (Jackson, 1984:68.)

Such discrepancies are a logical consequence of a system where the large informal role accorded to women in economic transactions does not extend to the legal and formal spheres, where men retain the ultimate authority. On most "official" matters, outsiders deal with male members of the household even when the issues at stake are central to women's well-being. For the most part, Africa's extension services, its court systems and its health care delivery services are staffed by men. Even in countries like those of West Africa where women were traditionally traders, they lack the skills and recognition needed for access to the formal channels for marketing and credit (Caughman, 1981; Keita, 1982). The cooperatives established under various colonial regimes had as members the male heads-of-household, and employed male officials. Similarly, then, when outside agencies have organized irrigation projects, they were directed toward dealing with male representatives of the household rather than toward the women, whose farming activities produce the larger share of Africa's food.

Impact of Irrigation Schemes

The introduction of irrigation in Africa means that a labor-intensive crop is superimposed upon a family's activities, without fully displacing existing food production. The things which African men often expect their wives to do within the farming system--selecting seed, tranplanting (if required), weeding, bird-scaring and harvesting--are vitally important for the success of irrigated crops. And yet, paradoxically, women have little claim on the returns, while their own household situation is made more difficult. The family requires more purchased food (to offset diminished effort on traditional crops or because in scheme environments food crops are excluded), firewood becomes difficult to obtain, there is less opportunity for ancillary livestock enterprizes and the incidence of parasitic diseases rises. In those instances where a scheme also markets the irrigated crop, payment usually goes to the tenant and not his wife. While on the one hand irrigated production demands a tightly integrated household labor force willing to work very hard at certain times, on the other the environment created within many schemes is unattractive to women despite its "modern" appearance.

The specific impacts upon family life which have tended to accompany externally introduced irrigation schemes include:

- Most African governments deal primarily with <u>men</u> when allocating water and land rights.

- The weeding of canals becomes very difficult to organize in those systems where weeding was traditionally a woman's task.

- A man's commitment to irrigation will often be a speculative investment undertaken without his wife's approval and intended for his own private profit. This, of course, ignores the practical consequence that irrigated production requires a large input of family labor.

- Household plots within large irrigation schemes often lack the basic amenities such as nearby fuelwood or opportunity for keeping smallstock, which are of significant concern to women.

- When a man dies, his claim to a plot, the growing crop or a water right may be transferred to another male kinsman rather than to his widow and her children.

- The situation of polygamous unions presents especially knotty issues concerning distribution of profits and inheritance within irrigation schemes.

- Extension and credit tend to be channeled to the men within a scheme, with the effect that those who need these inputs most do not obtain skilled advice or critical financial support.

- Increased incidence of diseases (like malaria or schistosomiasis) which accompanies irrigation will increase the time a woman must spend caring for those who are sick, limiting her own work input.

- Adoption of labor-intensive crops for the irrigated cycle, such as rice or cotton, will accentuate the demands made upon a woman's time at periods of peak labor requirements.

- A concentration of grain production in large open fields attracts enormous flocks of birds. Traditionally, bird-scaring was often left to women or children.

- To attract outside laborers needed at harvest, farmers usually offer food and beer as an incentive. Once again, preparing this food was a woman's task within the existing farm system.

- Preparation of rice by hand is a labor-intensive task much disliked by women, but one which becomes even more important in the environment of a formal scheme.

The greatest adverse impacts appear to be associated with large schemes where women gain admittance by being wives of tenants. Examples would be the situation of women in Kenya's Mwea and Bura schemes (Hanger and Moris, 1973) and within Sudan's New Halfa Scheme. Salem-Murdock points out (1979) that women coming into the New Halfa Scheme suffered from a loss of milk consumed in the household, cash which they formerly obtained through sale of surplus milk, fuel rights and access to land.

The degree of intra-household stress being generated by poor project design will not be fully evident from the meetings which the scheme or project mangement holds with male "farmers." High rates of marital instability may seem part of the "normal" African social pattern. It is only when the situation gets so bad that the labor supply dries up or women organize a mass boycott that the scheme managers may begin to take women's grievances seriously. The fundamental problem is that often women have insecure access to returns from their work, and to control over household improvements (if the housing is on scheme land). The unpaid resource transfers which are assumed to occur freely within a "family farm" can easily become exploitative under the typical circumstances encountered within African irrigation projects.

However, similar difficulties can arise even within small-scale, spontaneous forms of irrigation development. Because in many African systems of land tenure women hold their plot rights <u>through</u> male kinsmen or affines (relatives by marriage), there is often a danger that once land becomes valuable it will be denied to women, even in contravention of "traditional" custom. An illustration of what can happen is provided from the Kore Smallholder Rice Scheme in western Kenya, where some 60 hectares of rice fields have been developed by the people themselves in a local swamp:

> The land tenure issue gives rise to a number of question-marks since the project area seems to be owned by only a few family clans. But who are the actual <u>cultivators?</u> What are their land-use rights? Adult men tend to prefer off-farm income opportunities and women constitute the majority of the farming labor force on their husbands' plots. On the other hand, women traditionally have definite land-use rights ('women plots') which are even inherited by their children. The Kore case study, however, reports that those traditional rights are becoming less secure as land is becoming a marketable asset. (Kortenhorst, 1983:6)

In this regard, it is instructive that within all five of the irrigated rice schemes studied by Dey (in Senegal, Mauritania, Zanzibar, The Gambia, and Burkina Faso), she found that:

> . . . the development projects deliberately handed over the improved land to the male household heads even though in all these countries women had hitherto been exclusively responsible for rice production and had often had independent rights to rice land. (Dey, 1985:435.)

The conclusion one can draw is that the implementation of donor-assisted rice projects generally results in dispossessing the very people who within indigenous sytems know the most about how to produce rice. Dey's own extended analysis of attempts to "improve" indigenous rice farming within The Gambia (1980, 1982) is a particularly telling indictment of "top-down" irrigation planning.

Desirable Design Changes

From a policy standpoint, one can identify a number of changes in scheme design which would greatly benefit women:

- Free family labor should not be assumed when appraising the between costs and benefits at the household level.
- The location and size of houseplots should be carefully considered when planning the irrigation layout.
- Attention must be directed toward the circulation of drainwater and the likelihood it will be drawn upon for household consumption.
- Canals should be designed to allow access from the withdrawal of household water--which will occur whether planned or not--and for the safety of children (two contradictory requirements).
- Since African families will keep livestock, the physical layout should anticipate stock movements and thought should be given to using ratoon growth (and other options) for forage.
- Large, uninterrupted field blocks without sanitary facilities guarantee the perpetuation and spread of parasitic diseases. Good layout means taking public health considerations seriously.
- The rights to houseplots (and hence, house improvements) should be held separately from those giving access to irrigation water, so that families have an incentive to make their own home improvements.
- A man's women and children should be listed as co-right holders in his shares of water, land or crop returns. Inheritance regulations should favor household members over other relatives.
- Special programs' employing female extension staff can be organized to upgrade women's understanding of irrigation practices.
- Access to credit and scheme services can be offered to rightholders irrespective of gender, so that the needs of female-headed households automatically receive equal consideration.
- The great importance of certain horticultural crops (bananas, manioc, spices, fruits and amaranths) in the family diet should be recognized. Given the high productivity of these plants to modest inputs of labor and water, their production should be assisted.

- The allocation of plot and water rights should assume households of varying size and composition, automatically accommodating to either growth or decline in family size.

- An increased level of environmental monitoring, disease treatment and public health education must be built into any larger scheme from the very start.

- The freedom to do their own processing of food and grains is very important to women. If controls on the disposition of the irrigated crops must be imposed, they should be carefully thought through from the standpoint of their impact on household welfare.

- Assistance should be given to establish rice milling facilities within local communities.

If we weigh these proposals individually, they do not seem impossible demands, nor would they be extremely expensive to institute. Many are already a part of the rural system in irrigated communities of developed countries. They are technically feasible, and they could become a routine part of African-irrigation planning if there is adequate recognition of their importance. For example, virtually all the women Dey visited mentioned their need for grain mills:

> Pounding grain by hand is a most tiring and time-consuming task, often carried out in the early hours of the morning when the men and children are still asleep or after dark when the women have returned exhausted ... Even men quite commonly mention this problem, but they are not prepared to spend their money on buying this labor-saving equipment for the women. (Dey, 1985:435)

Unfortunately, in aggregate such changes represent a different set of priorities from what is usually encountered in irrigation planning as it presently occurs in Africa. The conflict is especially sharp in the larger, heavily bureaucratic schemes where the irrigation authority controls farmers' settlements as well as the delivery of water. We have argued that this linkage is not necessary: there are other ways available for recovering water delivery costs. The increased degree of control over farming which African irrigation agencies seem to desire can only be realized at a heavy cost in creating unnecessary rigidities and dependencies, and in sharply decreasing the benefits scheme families enjoy. The ironic fact is that changes which would assist women also make fieldwork more tolerable, reduce alienation, improve morale and raise the quality of life for all scheme members, male or female.

Pastoralism and Irrigation Development

In Chapter Four, the "problem" of livestock was touched upon, since this is indeed how technical staff view animal production in the scheme environs. However, it is also true sociologically that often the people who are supposed to take up irrigated production have come from pastoral backgrounds. The lack of congruence between the attitudes and skills required for successful pastoralism and what is needed in irrigated farming is extreme. Put very crudely (since there are many varieties of African pastoralism), the difference is that pastoralists must remain highly mobile, have minimal fixed investment in houses and equipment, utilize a very large area, and show a high degree of flexibility and independence. Irrigators, on the other hand, have a large fixed investment, use a small area intensively, are tied to growing crops and must closely synchronize some activities with their neighbors. The habits of thought and action required for successful irrigation are antithetical with those needed for success in pastoralism--a discordance which explains much of the low performance which results when pastoralists are expected to become irrigation operators.

The involvement of pastoralists occurred initially when a number of Africa's larger schemes were located in "unused" pastoral rangelands. Notable examples were the Office du Niger in Mali, the Gezira, Rahad and New Halfa Schemes in Sudan, and the Pekerra, Mwea and Bura settlements in Kenya. In our earlier discussion, we pointed out that these are only a few of the many examples: virtually all irrigation development in the semiarid lands of Africa has taken place on prime rangelands. The general lesson from all of these projects is that local pastoral populations have shown little enthusiasm for joining officially-sponsored irrigation projects. As a consequence, even when located within pastoral areas, Africa's larger irrigation schemes have been settled by outsiders.

Large-Scale Schemes: The New Halfa Case

To illustrate the complications which arise for pastoralists when a large-scale scheme is located in their midst, let us take the example of Sudan's New Halfa Scheme, formerly known as the Khashm el-Girba Scheme. The task is greatly facilitated by the fact that the New Halfa Scheme is by far the best documented case of attempted sedentarization of pastoralists by means of large-scale irrigation development (Agouba, 1979; Dafalla, 1975; Salem-Murdock, 1979, 1984; Fahim, 1980, 1983; Sorbo, 1977, 1985; Hoyle, 1977; Pearson, 1980; and Shepherd, 1985).

The flat Butana plain of eastern Sudan where New Halfa is located consists of a vast expanse of mostly treeless, clay soils lying between the Atbara River on the East and the Nile on the West. Historically, the area was known as a "land of thirst" (Balad el attash), where little water could be found away from the major rivers during the months from March to July. Rainfall in the North is as low as 75 mm per year, dictating camel-based nomadism as the traditional livelihood, increasing gradually to about 500 to 600 mm in the South, where mixed herding of cattle, sheep and goats occurs in an acacia studded savanna environment. About 20 different groups of pastoralists inhabited the Butana plains, with the Arabic speaking Shukriya numbering between 300,000 to 500,000, being the largest.

This was the land, then, chosen by the Sudanese Government for resettling the Nubian people of Wadi Halfa, whose holdings along the Nile were flooded by the Aswan High Dam. However, a very large area to the South (2,600,000 feddans officially demarcated by 1979, and almost as much under unofficial use) was taken up for mechanized large-scale rainfed cultivation (Shepherd, 1985). This squeezed the existing pastoral peoples northward into the drier zone of the Butana itself, where from the mid-1960s onward the Sudanese Government took a further half-million feddans for establishing the New Halfa Scheme. The project area stretches some 100 km along the western bank of the Atbara River, from which it draws its water by a dam not far from the Khashm el-Girba settlement. About half the 300,000 people inhabiting the Scheme in 1978 were ex-nomads; of the official tenants (in contrast to the freeholders from Wadi Halfa), almost two-thirds (63 percent) were from a pastoral background (Sorbo, 1985).

The New Halfa Scheme has become a key example of the Sudanese Government's attempts to sedentarize its pastoral populations. However, initially all the attention and most of the benefits went to the relatively urbanized "Halfawieens," most of whom were opposed to being resettled at Khashm el-Girba (Fahim, 1983). As a consequence, the Wadi Halfa settlers received freehold land (twice the surveyed size of their original holdings), houses and village services (schools, water and health). In marked contrast, when ex-nomads were recruited in later phases of scheme development (1967-69), they received neither village services nor houses, and became tenants rather than freeholders (Pearson, 1980). This solution left both major groups who live in the scheme feeling cheated, with each group claiming a moral right to lands it had lost. Despite the scheme having been in operation for over 15 years, neither the "Halfawieens" nor the ex-pastoralists regard it as their permanent home (Fahim, 1980).

For the ex-pastoralists, the crucial issue was whether life in the scheme could provide a viable livelihood. Almost all hedged their bets by continuing to keep substantially more animals than the one animal unit per fifteen feddan holding which is permitted under the tenancy agreement. Tenants' animals are allowed to graze the banks of canals and on land not being cropped, but are not supposed to enter the fields until after crops are harvested. In practice, it has proven impossible to determine the real numbers of animals a household owns, since at different seasons they are transferred in and out of the scheme and many tenants own substantial herds kept outside within the Butana (Pearson, 1980). It also happens that nomads from outside the scheme bring their herds into the fields at night in search of fodder and water. Some tenants claim there are western Sudanese who have established themselves on the scheme boundaries and who sell dairy products in New Halfa in competition with the "Halfawieens" who can keep as many animals as they wish on their freeholdings. In any event, during the long dry season, and especially in times of drought, trespass becomes a major problem. The scheme's management has regularly called upon the police and even the army to protect growing crops (Pearson, 1980).

Sorbo (1977, 1985) provides detailed analysis of non-agricultural incomes and the growing socioeconomic differentiation within the Scheme area. The Nubian "Halfawieens" have in fact done quite well. New Halfa town, with 35,000 residents (in 1978) and a range of subsidiary occupations and services, is more than three times the size of old Wadi Halfa. Among Butana's original inhabitants, the main advantages have gone to the traditional elite who received first claim on tenancies and who have accumulated fairly large holdings and herds. There has been a large increase in numbers of animals using the Butana plain, by outsiders as well as original inhabitants, leading to a serious deterioration of pastures (Shepherd, 1985). For smaller households, livelihood from the scheme remains marginal. They are only able to survive by mutual transfers of resources between irrigated agriculture and the livestock sector, and by working as hired laborers for larger households.

Small-Scale Irrigation for Pastoralists

The more recent involvement of pastoralists in irrigation projects has come about as an indirect consequence of major African droughts, particularly in 1972-73 and 1983-84 (affecting most of the Sahel and Horn of Africa), but also localized droughts (such as in 1979-80 drought within northern Kenya). What typically occurs is that as food supplies fail within an area, various NGOs and national agencies become involved in distributing famine relief to destitute ex-pastoralists. Within the most severe droughts, livestock either die or are driven out of the area in search of better pastures. If the able-bodied men have left with the surviving animals, those remaining at home will be the aged, the women and their children. Such populations quickly become entirely dependent on externally supplied food and many may die when the food distribution system for one reason or another fails.

It is easy to see why irrigation can appear an attractive solution to a relief agency which finds itself supporting ex-pastoralists at remote locations within the semiarid zone. For people to live in famine relief camps there must be a water supply, a prime consideration in the siting of food distribution points. As the immediate crisis passes, the water availability will improve, while at the same time external food supplies become more erratic even though the most destitute residents of a camp will remain, having lost the herds which allowed them to participate in the pre-drought economy. Willy-nilly, the relief agency, finds itself still entirely responsible for the feeding of a sizable community which could be producing at least some of its own food within the immediate locality.

A good example is provided by Helland's (1980) case study of a drought rehabilitation project for the 'Afar people of northeastern Ethiopia after the 1972-73 drought. Within the area he studied there were some eight irrigation projects established, based on flood irrigation of maize or sorghum for 2,000 people. Participants received 3 kg of grain daily, irrespective of either their work or the success or failure of irrigated farming (Helland, 1980). This was, of course, very popular with the semi-nomadic 'Afar, who then put their least productive members, such as old women and children, into the schemes, while the menfolk continued in livestock production. This facilitated a rapid recovery of the 'Afar herds and disguised the fact the irrigated plots "were never viable economic enterprises but were heavily subsidized by relief supplies." Helland concludes:

> Some of the irrigation projects initiated during the initial phase have been discontinued, mainly due to technical problems involving the control of the flash floods. In several project areas, fields have been washed away and barrages and diversion channels have been destroyed and no crops have been harvested after three or four years of operation. Nevertheless, these projects still seem to be attractive to the 'Afar and there is no lack of participants. (Helland, 1980:123.)

A number of additional examples can be found in the dry areas of northern and eastern Kenya. Some of these small-scale projects depend on "boreholes" (tubewells in Asian parlance), but more typically they use small diversion canals from seasonally-flowing rivers that originate in higher rainfall areas. Three such schemes, at Katilu, Amolem and Kakorongole, constitute the "Turkana" cluster (though the Amolem scheme includes a higher proportion of West Pokot people). The Katilu and Amolem projects are described by Schwartz (1983), Broche-Due (1983), and Broche-Due and Storas (1983).

Irrigation was introduced into this part of northern Kenya by NGOs in the late 1960s. Subsequently, a national steering committee was set up, which led to Ministry of Agriculture involvement throughout the 1970s and eventually to UNDP/FAO assistance, following in the late 1980s by NORAD assistance. The schemes which remained, primarily NGO efforts, have stayed small and simple, at around 30 ha (considered the "ideal" size by NGO staff involved with such projects). Katilu Scheme, however, which became the focus of FAO/Ministry of Agriculture efforts, was provided with heavy equivalent, pumps and a ridge-and-furrow system of water allocation. It had been intended to irrigate almost 500 ha. A total investment of about seven million dollars to serve 710 tenants on onehectare plots was anticipated for the three "Turkana" cluster projects. The Ministry appointed its own staff to operate the scheme, which was supposed to grow cotton as a cash crop to repay costs and maize, sorghum and green grams as food crops.

Achievements in practice have been much less than planned. The information provided by Schwartz (1983) is summarized for Katilu and Amolem Schemes in Table 40. Plot sizes have ranged between .2 and .5 ha, with maize grown for home consumption being the main crop, but some cotton also grown at Katilu. Breakdown of pumps, inability to get diesel and spare parts for machinery, a high rate of absenteeism and turnover among Ministry staff posted to the area, and the flooding in 1981 of some 60 hectares of newly leveled land, have necessitated a shift to a much simpler system based on a gravity fed canal and basins rather than furrows. Since the schemes are located in the riverine thickets which are also the main source of dry season browse and water for both wild game and cattle, losses to the crops by depredation have been substantial and yields low. The destruction of trees bordering the river and intensified land use have caused changes in the riverbed, resulting in destruction of the intakes and siltation of the supply canal. The

TABLE 40

TURKANA CLUSTER SCHEMES

Scheme	KATILU	AMOLEM (AMULEM)
Date begun	1970	1976
Predominant groups	Turkana	West Pakot
Size	220 ha	30 ha
Plot size (mean)	0.5 ha	0.2 ha
No. tenants	450	150
No. laborers (food for work)	300	250
Famine relief recipients (approx. no.)	2,500	1,500
Total population of settlement	8,000	5,000

Source: Sabine Schwarz (1983). "Irrigation in Arid Areas--Its Limitations and Its Rejection by Nomadic Pastoralists," In: Man and Technology in Irrigated Agriculture, DVWK Bulletin No. 8, Hamburg: Verlag Paul Parey, p. 194.

Ministry, with FAO/NORAD assistance, has tried to devolve managerial responsibility on a growers' committee, which is supposed to recover its cost from a cess on the cotton grown. However, cotton prices have been low, the quality and yield disappointing and the marketing parastatal delinquent in making its payments to farmers.

The more basic question is what some seven million dollars of external assistance has gained for the pastoralists themselves.[1] The Turkana and other peoples like this have been the almost continuous recipients of external assistance since the mid-1960s, with about one-third the total district population still receiving food relief in the early 1980s. As Schwartz notes, the Turkana have been opposed to external political control but receptive to economic assistance, taking up in turn whatever donors have suggested: irrigation, water harvesting, camels, milking goats, etc. Households on the schemes are nearly double the average size, and also own livestock away from the scheme (Schwartz, 1983). They continue to make livestock payments required of them under traditional obligations, using their profits to reinvest in livestock. When gold was found in the early 1980s, 60 to 70 percent of the farmers abandoned their plots and new plotholders had to be recruited. The concentration of people and animals around the schemes has caused the destruction of the trees and the rangelands leading to "over-crowding, over-grazing, shortages of water and fuel, with the attendant social problems of crime, alcoholism and prostitutes" (Schwartz, 1983:206).

Some Lessons for Pastoral Development

Operational lessons from Kenya's drought relief irrigation projects have been summarized by Kortenhorst (1983) and Asmon et al., (1984), and are itemized at the close of this chapter. Specific to projects aimed at employing destitute pastoralists, there are several further observations one might make:

- Men of a farming age whose labor input is essential are the most likely to be attracted elsewhere in response to temporary opportunities. The instability of family groups may make it necessary that plots are given to individual adults as their personal responsibility.

- In a dry environment, springs and riverbeds where water can be found will also constitute critical sources for wildlife and semi-nomadic pastoralists. Other users' needs must be reckoned with when laying out small-scale irrigation.

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[1]Schwartz itemizes just under four million dollars contributed to Katilu and Amolem projects by ten donors during the period from 1966-1981. More recent tabulations of total cost for the Turkana cluster by the Kenya Ministry of Agriculture and by FAO/UNDP staff indicate well over seven million dollars if one includes staffing costs.

- Fuel and parts to keep pumps in operation exceed what small communities in remote locations can organize for themselves.

- Irrigation depending upon imported pumps should be avoided.

- The "cloudburst" nature of rainfall in dry areas means that intake works and canals are frequently damaged by flooding. Either intakes should be sited to minimize this danger, or they should be constructed of traditional materials which can be locally repaired each season.

- The amount of labor a woman and her children can contribute to farming is very small. A plot of 0.1 or 0.2 ha may be all such households can manage effectively. Asmon et al. (1984) suggest plots of half an acre should be allocated per adult. It is essential enterprises are chosen to minimize cash and labor inputs.

- Security for crops and household members is often at issue in the environments where ex-pastoralists are found. These risks should be assessed when locating and planning schemes.

- Ex-pastoralists require more training and closer supervision than would otherwise be the case.

- If households concentrate upon meeting subsistence needs, it can be predicted they will have little surplus production to sell. Any services requiring cash payments from them will be a source of continuing difficulty.

- Settled households depending on cereal foods require far more firewood than do semi-pastoral households relying on milk. Adequate provision of fuelwood is an essential part of any long-term sedentarization.

- Outsiders should expect that a great deal of effort will need to be devoted to encouraging leadership skills within the project community. Among the hardest skills to convey are those associated with accountancy and the control of common savings on behalf of project members.

Conflict Resolution

The sources for conflict associated with the practice of irrigation are many and varied. As a heavy user of a finite and often scarce resource, irrigation development embodies claims which will often be controversial and subject to dispute. As implemented in Africa, formal irrigation schemes have been imposed upon pre-existing systems with little consideration of what will happen to those whose rights are extinguished. Sometimes without consultation whole communities will be relocated and permanent structures constructed on the lands people once thought they owned. On many of Africa's rivers the extended period when water levels are low is already a time of hardship; unanticipated diversions to permit irrigation at points higher in the system are bound to increase tension. Then there is the issue of what to do about pollution which surface irrigation may return to the river system via drainage lines. In general, irrigation changes the distribution of benefits in the local system, and is frequently a source of new conflicts.

The amount of conflict associated with water management is a function both of water scarcity and of the particular design of the distribution system. Obviously, it will also reflect (inversely) the degree of consensus among users concerning how water should be allocated and what exceptions are legitimate. Where the allocation system is perceived as being fair or necessary, conflict may be low even when water is scarce. For example, in the huge Gezira System by long convention tail enders are allowed to withdraw their water first; similarly, "indents" (orders) are accumulated from the outermost sections back to the main canal in such a way that those nearest the source must absorb any shortfall which occurs. The sociological fabric of understandings within a system about who gets water when, where, and why is therefore a key determinant of the level of conflict actually evidenced.

When conflicts erupt, they can occur at different levels within the system (and thus require different conflict resolution mechanisms): between adjacent or neighboring users on the same tributary (the age-old tail-ender versus front-ender problem); between competing segments or villages on different secondary canals; between farm tenants en masse and the water authority; or even between different countries sharing the same river system (e.g., Ethiopia and Somalia). At whatever level, water-linked conflicts can be taken up under a variety of organizational settings--some more effective than others in achieving a lasting resolution. They may be dealt with as ordinary civil cases within the judicial system; alternatively, they may be the reason for activating traditional dispute containment procedures, e.g., by clan elders in a village; or they may be categorized as a "water dispute" under separate regulations and jurisdiction. What seems to be generally absent in Africa are recognized traditional roles assigned the special duty of administering water rights--most likely a reflection of the limited use made of irrigation (except in Madasgascar and the Arab-influenced northern countries). Given the array of other possibilities for handling water-related disputes, it is likely that both the incidence of conflicts and the devices employed for resolving them will strongly reflect cultural patterns in the surrounding area except insofar as the state itself becomes an interested party.

Evidence of inadequate adjudicating mechanisms can take several forms. In extreme cases, there may be actual violence (see the Bakolori case given in Chapter Three). There may be damage to canal systems, giving excluded farmers access to water. Alternatively, farmers may refuse to pay scheme charges or may withdraw completely from joint activities such as canal maintenance. Poor communication and a lack of mutual confidence between farmers and irrigation managers is common with large, bureaucratically controlled irrigation schemes. Some of the more apparent problems of irrigation, such as delinquent loan payments or the rapid deterioration of physical structures may in actual fact originate from high underlying levels of tension, which in turn reflect unresolved disputes. The particular layout of the water distribution system is also significant. Some systems pit farmers and groups against each other in ways which continuously fuel competition when water becomes scarce. The conflict-generating implications of alternative methods for water distribution ought to be considered when doing the initial design. Since irrigation involving smallholders usually requires a high degree of voluntary cooperation, a failure to resolve conflicts--whether initially or later during routine scheme operations--can cripple irrigation efficiency.

A significant feature of African social systems is that a person's ethnic (or "tribal") ties have a great deal to do with how disputes will be treated. Disputes involving outsiders--especially if they are powerful, tend to be handled within the court systems, but disputes between fellow clansmen are often acted on by village elders outside of the formal system. The difficulty on Africa's larger irrigation schemes is that those recruited as tenants or as laborers frequently come from a distance, perhaps having a different language, culture and religion from what predominated locally. Where the original users of land were few--as will be the case if they were pastorlalists--the "outsiders" who enter an official scheme will soon outnumber them, and there may be a protracted struggle not over water rights per se (though these too can become an issue when the pastoral herds arrive at the water source) but between scheme tenants and the dispossessed right-holders. For example, on both the Gezira scheme and the Office du Niger, a substantial number of those receiving plots or working in the irrigation systems were not even from the same country as previous residents. A polarization between "locals" and "outsiders" is common within many of Africa's development projects, and puts a strain upon the formal systems for dispute resolution, which are not well suited for dealing with water-related conflicts.

The basic situation is that where local farmers--strangers or otherwise--hold such tiny plots (of one hectare or less) and are there by bureaucratic sufferance or through undocumented oral agreements, they have very little leverage against the scheme or irrigation authority. Recourse to the "paper" system of tribunals and formal hearings will only be effective if the claimant has backing from above (e.g., a "big man"). On their own, farmers may not expect a fair and impartial resolution of their disputes. In much of Africa, "paper" justice is still associated with the colonial past and with the arbitrary exercise of raw political power. Thus enactment of water laws at the national level is usually an ineffectual device for improving dispute resolution locally.

Here those communities which were already involved in traditional irrigation have an advantage, e.g., the Taita of Kenya (see Fleuret, 1985) or those living in the wet-rice zone of Madagascar. For the remainder of Africa, the introduction of irrigation necessitates that measures for conflict resolution be instituted. Otherwise, the spread of the technology may be curtailed. An excellent illustration is furnished by Roder describing the initial spread of irrigation in Zimbabwe:

> Since the Shona had no history of irrigation, they had no customary concepts of water appropriation. At Mutambara the participation of a strong chief ensured that inevitable disputes over water allocation found a court settlement. This is not to imply that land and water were evenly distributed; rather, it appears that the chief and his relatives took a lion's share.... Where traditional leadership failed to combine with new learning, water disputes are argued by force rather than settled, as every man felt entitled to use water as and when he pleased. Informants tell of getting to their fields early in order to be first when opening inlets and of ensuing fist fights with late comers who thought their supply curtailed. Lack of agreement...probably prevented the growth of other irrigation projects greater than those managed by one or two families. (Roder, 1965: 99-100.)

A similar situation arose more recently within Senegal:

> ...near Rossa, a group of former slaves set up an irrigation project on dry steppe land. They believed their tenure was secured by the work they put into developing the land and the government's grant of the land to them for that purpose. However, when harvest time came, the head of the local Moor community arrived to claim his half of the yield. His ancestors had conquered the area and he had papers from the colonial government to confirm his title. The local gadi (Islamic judge) ruled that the documented historic claims outweighed the more recent government grant. (USAID, 1983, III:107)

On a visit to Mali's Bandiagara Plateau in mid-1983, we observed one village where despite the onset of the summer rains (in a very dry year) the removable gates on a small dam had not been installed because of a continuing dispute between villagers and the three families claiming the land which would be flooded.

One can assume, then, that peasants with conflicts at the local level will choose their own means for obtaining redress: perhaps witchcraft accusation, social ostracism, expulsion of the offending party, the levy of a fine by the elders, or even physical violence. Use of written legal precedents will be confined to the educated elite, or, more commonly, to the government's own efforts to increase its control over farmers' land and water. When high status outsiders do take legal action, it may well be to use their superior grasp of legal procedure to dispossess rightful claimants (Francis, 1986). A major weakness of present systems in much of Africa is that traditional claims upon land and water lack the formal documentation needed to support legal action in a "modern" system. As Chapter Seven shows in regard to land tenure, there are many contradictions and ambiguities in the evolving system. Rights of easement, sharing of profits, inheritance by women and minors, and the temporary use of land all occur commonly, but on the basis of social convention rather than with the written protection of the law.

The Islamicized areas of Africa--where the larger share of the continent's present irrigation developments are found--are a partial exception. Islamic law is accepted and used at the local level in many transactions involving property and inheritance. Religious leaders at the village level may wield a great deal of power, being the key persons in dispute resolution. Here, too, the disjuncture between what is accepted practice locally and what appears in the national legal codes may be less. The provisions of Islamic water law are well documented in the literature[1], and it would make an interesting comparative study to see to what extent levels of conflict are lower in Muslim communities. Elsewhere, Party officials sometimes play this role in the socialist countries (especially in Ethiopia and Tanzania), as do the Village Headmen or Chiefs in central and southern Africa (Malawi, Swaziland).

In the last analysis, then, it is likely to be the people's own institutions--the degree of trust shared between them, an absence of pronounced inequalities, a recognition that they have been fairly treated by the government, and the acceptance of certain rules for settling water-related disputes--which minimize friction in irrigation management. Because there is no one specialty which addresses such topics at the preliminary stages when projects are being designed (where economists often substitute for other social scientists), very little is known about this aspect.

The Bureaucratization Issue

The commitment of funds to irrigation usually means adoption of the project mode: designation of specialized management, appointment of salaried staff, identification of target outputs phased over time, and perhaps acceptance of external evaluation. These features have become the standard format for technical assistance interventions during the past three decades--becoming in effect an "embedded model" about how development should be done--but nonetheless constitutes a marked change from what would be necessary if irrigation were adopted mainly at farmers' own initiative. In particular, the involvement of external financing on larger projects brings with it many additional requirements: legal recognition, conditions precedent, disbursement and accounting procedures, and so forth. These requirements virtually guarantee that the implementing agency is itself a bureaucratic unit.

The "embedded: bureaucratic mode of doing business comes with its own set of problems, problems better recognized by farmers than by planners. Perhaps the most obvious one is the need to achieve a relatively high volume of production before the turnover can repay staff salaries. There is in many African countries a long tradition (going back to colonial times) of employing people in specialized, low-level occupations: drivers, mechanics, pump operators, water guards,

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[1]See particularly a series of FAO reports by Caponera (1973, 1978, 1979, 1981).

accountants, and the like. Establishing a management unit for even a small perimeter will generally require from 5-10 people, not the one or two its output can support. While individual salaries may be relatively low, when these are linked to a tradition of inflexible job assignments, the overall unit costs of production become quite high.[1] It is astonishing just how persistent such "management" units can become. Kenya's Malka Dakaa Scheme (described below) when visited in early 1987 still had a full complement of salaried staff even though no water had flowed through the furrows for several years and there were small trees growing in the dry canal beds. Across Africa one encounters many similar projects, where Ministry staff remain in place on largely defunct irrigation perimeters.

The employment of salaried staff can also mean the appointment of outsiders who share neither farmers' languages nor their social background. As already noted, tribalism is the scourge of the African continent. It is not so much a survival or traditionalism, but rather an emergent politicization of a person's linguistic identity to become a badge of group membership. Because access to western education is not evenly spread between all tribal and religious groups (with pastoralists and Muslims often being underrepresented), when employment is based on educational attainment it will in practice result in bringing outsiders to become scheme staff. Such individuals are commonly younger men who had hoped to progress into higher education and who still aspire to an urban standard of living. Some are themselves from an urban background, and many have been away form rural life for extended periods while under training. Their divergence in attitude, language, education and farming experience from their supposed clients becomes a potent source of alienation on both sides. Overlaid upon and reinforcing these sociological cleavages is the fact that often project objectives had been set to serve national interests which diverge sharply from what may be in the farmers' own best economic interest (Faki, 1982; Trilsbach, 1986).

The divergence in production objectives becomes translated into specific grievances through the application of official decision-making and bureaucratic rules. Ironically, this outcome is precisely opposite from what theoreticians would have predicted. The sociologist, Weber, saw bureaucratic decision-making as being based on expert, technical knowledge; it would be, then, less reflective of politics and favoritism. However, in a rural African setting, a project's salaried staff control access to many benefits. They may allocate the best plots within the water distribution system to themselves or their relatives. They may divert fuel and water intended for scheme use to non-scheme, private irrigators (as Trilsbach notes for Sudan's Qoz en Nogara scheme, 1986). Government officials may insist upon legal proof of ownership before

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[1]Here, see discussion of this problem in relation to ranch management given in Moris, (1981:56-57). The effect of a high cost operational structure of this type is to make it impossible for field production units to be grown incrementally from a small beginning. Instead, to cover costs a perimeter must achieve high volume output from the start (with all its attendant risks).

paying compensation to those dispossessed from their fields, thereby disenfranchising those who are not skilled in manipulating the paper requirements for establishing legal claims in the "modern" national system. Each procedural step--of which there are hundreds required for the normal operation of a complex production system--can become a potential obstacle, requiring pleading and bribes and gifts before officials take action.

Such tendencies are reinforced within irrigation projects because of their high costs, the need for specialized surveys, and the fairly substantial construction component when laying down the distribution network for surface irrigation. Would-be tenants find that in joining an irrigation project they are forced to deal with an array of bureaucratic service institutions not only to acquire land and water but also for seed, land preparation, credit, inputs, and marketing assistance. These requirements can become so burdensome that tenants view themselves as being government laborers, a perception Belloncle reports for Sahelian schemes but one which is also widespread in East Africa.

On the Mwea Settlement in Kenya (as on the Gezira in Sudan), one finds that the tensions between farmers and staff have become crystallized into two, contrasting images of scheme life (Chambers and Moris, 1973). Official visitors are told what can be termed as "management myths," stressing the scheme's technical achievements and the consequent well-being of its "fortunate" tenants. However, behind the scenes one will hear equally persuasive "tenant myths" which highlight the hardships of living in a malaria-ridden environment and with the relatively low real incomes which tenant families enjoy. Perhaps neither viewpoint constitutes a balanced picture of what actually transpires within a complex and large undertaking, having diverse positive and negative impact. Evaluation becomes quite difficult because in irrigation these impacts can be strongly divergent, with the increased commercialization of tenant farming being accompanied by high levels of indebtedness and deteriorating public health.

Trilsbach's review of administrative problems on Sudan's Qoz en Nogara Scheme (1986:59) illustrates the reason why its farmers remain "highly critical" of the White Nile Agricultural Corporation which manages the project. They claim administrators are "out of touch with the farmers' needs," fail to visit the scheme regularly, lack managerial skill, and some are even without such basic knowledge about the scheme as its size, tenant numbers, and crop water requirements. The project administration often fails to provide water during the season when it is required for farmers' valued dura crop. Land leveling done by the Corporation and charged to farmers is often poorly carried out, leading to large losses by individual tenants. Scheme staff permit illegal sale of water to nearby private schemes in order to boost their own incomes. The official labor unions are ineffective. Farmers believe the richest tenants are those with relatives in the White Nile Agricultural Corporation, which gives them and scheme staff the most favorably located plots (hawashas). Management decisions such as the abandonment of fallow in the rotation (yielding declining output) and a refusal to permit diversification into other crops are resented. The late delivery of fertilizers has severely depressed cotton yields, while the Corporation has been accused of being slow to pay farmers for their cotton. Farmers consequently experience serious cash flow problems. Trilsbach notes that since there are no formal lending institutions on the scheme, "farmers are able neither to finance adequately the inputs for the early part of the next season nor to arrange for work to be done at the best time." From a tenants's viewpoint, the resulting low yields (and hence returns) are largely caused by factors which lie within the Corporation's sphere of responsibility.

There are obvious analytic reasons for believing that farmers' rather pessimistic accounts of daily life within Africa's larger irrigation schemes are nearer to the mark than the managerial views represented in most official report. The underestimation of production costs by managers (and appraisal experts) has meant that the project benefits have taken much longer to materialize than planners expected. On the Gezira, for example, Sudanese investigators suggest that tenants obtained little lasting benefit before the late 1950s, when the scheme had been in operation more than two decades. Similarly, on Mwea in Kenya we found little to support management claims of tenant well-being by the mid-1960s when the scheme had been in operation for nine years--it took an additional 4-5 years before scheme benefits finally became visible (Chambers and Moris, 1973). In particular, the refusal of many irrigation agencies to acknowledge that tenants incur substantial labor costs is a major reason for the overestimation of farm-level benefits.

The high risks and relatively low value of official crops leave tenants with little margin of security should any support arrangements fail. High input farming under the high levels of aggregate institutional risk which most schemes encounter is almost certain to result in a fairly substantial number of seasonal failures for individual farmers. Mean output figures (as earlier noted) can mask the number of individual failures in each season (as well as of whole sections with very poor crop output). The burden of growing tenant indebtedness is seldom mentioned in project documents, but is a very real concern on many schemes at present. Sorbo cites figures given by Salem-Murdock for Sudan's New Halfa Scheme that in 1976-77 while individual tenant's gross returns were on average 144 Sudanese pounds, 110 pounds went immediately to repay individual joint account expenses and of the remaining 34 pounds tenants had still to repay their individual cotton account expenses (Sorbo, 1985:40). For poorer tenants, Sorbo found that scheme production frequently fell far short of a modest subsistence goal, "resulting in widespread, chronic dependence on private credit and subletting of tenancies" (1985:53). In the Office du Niger, out of 5,500 tenants 36 percent (about 2,000) were to receive nothing at all in payment for the 1983 season after deduction of expenses and the total tenant indebtedness to the Office had reached one half a milliard in Malian francs (Fresson et al., 1985:203). Richard Miller's observations about Bakel in Senegal can be taken as broadly representing the debt situation on Africa's formal schemes:

> Many peasants found it harder than they had anticipated to reimburse the debt incurred to SAED for supplying the agricultural inputs. Due to the heavy cash flow burden on the peasant, there had been a general malaise concerning the ultimate benefits of the irrigation scheme. The peasants feel that most of their time and effort goes toward debt repayment to SAED, with little compensation for themselves. (Miller 1985: 105-106.)

Any dense settlement of people on the flat, clay plains where most of Africa's larger schemes have been placed can become an uncomfortable and unsanitary place to live during the rainy season. The disease risks reviewed in Chapter Four are usually recognized by those living in the area, and constitute a negative feature the people associate with irrigated production. Many schemes have attempted to restrict farmer's growing of fuelwood, the keeping of livestock, and the planting of high calorie root crops (like bananas and tubers). They sometimes also impose small houses and tiny houseplots upon families, forcing people to live in what they consider are immoral circumstances (a finding encountered on Mwea in Kenya, where the original two room houses forced parents to share sleeping space with grown children). While some of these features become ameliorated as a settlement matures, others--such as shortages of fuelwood and overcrowding--may worsen.

It would be absurd to claim that life in an African irrigation settlement is necessarily unpleasant. The larger share of Sudan's modern economy outside of Khartoum is situated in and around its large-scale irrigation schemes, which have sent thousands of second and third generation residents onwards into colleges and university educations and eventual civil service employment. But for the poorer families with insufficient labor who remain behind, life on many of Africa's larger schemes is still not very different from how Sorbo describes it for the New Halfa Scheme in the early 1980s:

> Production was low; absenteeism was high; there were repeated shortages of water, vehicles and fuel; pests and weeds invaded the fields...required inputs of seeds, fertilizers and pesticides rarely arrived on time; poor storage facilities caused deterioration and losses; and tenant incomes were low and extremely irregular while production costs rose continuously. (Sorbo, 1985:40.)

Since such tendencies persist despite (and perhaps because of) the employment of bureaucratic scheme managers, reforms in how irrigation schemes are planned and operated in Africa are long overdue (here see Chapter Three).

For African irrigation planners, the bureaucratization issue needs to be dealt with more explicitly in three respects. First, it should be recognized that where new, "modern" projects are being interposed on top of existing, small-scale irrigation, the chances for misunderstanding and conflict are very great. The mistakes made at Bakel in Senegal and at

Bakolori in Nigeria were quite predictable in view of how irrigation projects are usually implemented (Adams, 1981; Beckman, 1986; W. Adams, 1985). Here we could learn from Siy's Philippine case study (1986), where because of the upheaval which occurred when a modern irrigation project was superimposed over traditional irrigation, the implementing agency re-assessed its approach and made significant changes even as the project was being implemented. The failure to do the same in places like Bakolori indicates just how serious the "bureaucratization problem" is within Africa.

Second, on Africa's larger schemes there is certainly room for a devolution of some scheme powers to farmers' own control. In Senegal, the term dépérissement is used to describe this objective (a term derived originally from Marx's concept of the withering away of the state under socialism). Bloch (1986:7-8) has argued that while some centralized initiative is probably necessary at the start, the field organization should anticipate and provide for its own disengagement from perimeter management once a perimeter becomes operational. In this regard, Korten (1982) and Uphoff (1985) warn that farmers' eventual involvement must be encouraged by their participation from the very earliest stages of project planning. Otherwise the procedural obstacles to their effective participation are so great they become alienated. When at a later stage scheme managers may wish to devolve functions upon farmers the farmers may have become so dependent upon the scheme and so distrustful of its management that such efforts will usually fail. Now that several African countries have attempted project devolution in one form or another, a sharing of this experience would be helpful.

Third, it should be recognized that the tendency towards increased bureaucratization is built into the very fabric of how modern specialized organizations operate. The two main causes of overbureacratization are farmers' needs for specialized services which they cannot easily supply on their own, and the government's need to recover its costs and hence to control farmers' economic activities. Bureaucratization becomes a problem, however, when the size of a project is too small to justify specialized assistance, and when the economic turnover cannot support a nucleus of several salaried staff. This is why "small-s ale irrigation" tends to become a topic in its own right when irrigation performance is compared between different systems. The technologies for moving water about the landscape are not greatly different in small systems, but the managerial and economic constraints are much tighter. From the many mistakes and failures one sees in the field within Africa's smaller irrigation perimeters, it can be concluded African governments still do not know how to sponsor efficient and effective small-scale irrigation. We turn, then, to this topic in the concluding section of this chapter.

Small-Scale Irrigation

Recent attention to small-scale irrigation in Africa is derived from the dissatisfaction of donors with the performance of their externally funded large-scale projects. The bureaucratic rigidity and high costs of these projects have become well-known (see Chapter Three). Donors have begun to ask whether a shift of assistance to smaller project or traditional irrigation might be more cost-effective. This conclusion was initially advanced by Carruthers and Upton in an unpublished FAO paper (1982), and reinforced by much subsequent work (Adams 1977 and 1981, Stern 1979 and 1981; Diemer and van der Laan, 1983; Belloncle, 1982 and 1984; Moris, Thom and Norman, 1984; Kay et al., 1985). Useful general reviews of African small-scale irrigation include Underhill's FAO paper (1984), Barnett (1984), a Silsoe report (1985) commissioned for IFAD; and the Harare Conference proceedings, African Regional Symposium on Small Holder Irrigation (Blackie et al., 1984) and Mock (1985). Looking at small-scale irrigation nearly a decade ago, Zondervan-Droz (1978) advised USAID that while such projects are not necessarily easier technically nor more equitable than large-scale projects, they are generally less expensive and more likely to gain local support.

Underhill (1984) makes the theoretical case in favor of small-scale irrigation. When suitably implemented, small projects may enjoy the following advantages:

- the technology is closer to farmers' existing knowledge;
- they are more sustainable and less import dependent;
- it is possible to mobilize local skills within the project;
- they are amenable to incremental implementation which allows "learning by doing;"
- there is usually no need to resettle families;
- they require a relatively minor degree of infrastructure;
- the low degree of investment means they have also a lower "success threshold;"
- the low dependence upon external inputs and skills yields greater self confidence; and
- investment is concentrated upon improving social organization rather than upon machinery.

These are indeed attractive benefits (particularly when seen in contrast to Africa's overly bureaucratic large schemes). As already indicated, it is also widely assumed that small-scale irrigation is cheaper than the large-scale alternative.

Actual Performance

The actual performance on officially sponsored, small-scale irrigation in Africa is not nearly as promising as these potential advantages suggest. By far the best known African example consists of SAED's small-scale perimeters in Senegal, where the Bakel project has been documented by a succession of observers (Adams, 1977 and 1981; Dubois, 1983; Franzel, 1979; Keller et al., 1982; Miller, 1984 and 1985; and Patterson, 1984). SAED had the misfortune to pick a perimeter where Adrian Adams, a resident social scientist, was in a position to observe and record what happened when a group of local farmers, already receiving assistance from a volunteer, came under SAED's official program. The Agency's ignorance of local conditions, its disregard of farmers' wishes, and its preference for a technocratic, "top down" approach are described at length in Adams' various writings. There should be compulsory reading for those intending to embark upon similar programs in other countries (see Chapter Three). A closely comparable instance also incorporated in our case studies is Mali's Action Blé-Diré, again a USAID assisted effort to get small holders into small-scale pump irrigation in an isolated environment.

At the other extreme, in an urban setting, we have Nelson-Richards' disturbing account (1982) of a small irrigation scheme started with political backing in a suburb of Lusaka, Zambia. Despite political patronage, high youth unemployment, and the proximity of urban demand for irrigated vegetables, the project still failed--largely, it would seem, because of the overly bureaucratic mode of its implementation.

Reference has already been made (earlier in this chapter) to schemes intended for introducing destitute pastoralists to small-scale irrigation (Helland, 1980; Schwartz, 1983; Broche-Due, 1983; and Broche-Due and Storas, 1983). A good overview of Kenya's Turkana experience is contained in Brown (1980). Equally instructive for our purposes here is the record of the Isiolo cluster projects (Arundale, 1978; Hogg, 1983, 1985, 1986 and n.d.; and Kuester and Wiggins, 1982). Within the Isiolo cluster are a number of small irrigation schemes, some started by the government, some by NGOs, and at least one (Garfassa) by local initiative. Hogg draws an illuminating contrast between the Garfassa scheme, which remains partially viable despite many setbacks, and the officially sponsored Maīka Dakaa Scheme, which is a complete failure.

Garfassa was begin in 1971 by a destitute farmer who had been refused admission into one of the other small schemes. Gathering his friends around him, he organized the digging of several small supply channels from the river to their fields. When others began to do the same, the group copied the nearby Bulesa Scheme and elected a Farm Committee to oversee the distribution of plots, the digging of irrigation ditches, and the allocation of water. Eventually, Garfassa contained several hundred people, each family with less than an acre, but achieving comparably high yields of maize for that area. In 1977, a major flood filled the supply canal with sediment and destroyed the intake, leaving the scheme without water for two years. During this time a new leader supported by the local Chief was elected, who rallied farmers and got assistance from the nearby Malka Dakaa scheme for equipment to clear out the sediment choked supply canal. A food-for-work program was started; and the scheme was brought under the government assisted Isiolo cluster. In asking for government help, the Scheme committee insisted that control over it would remain in their hands. In 1979 the canal finally became operational again, and for a brief period the scheme resembled one of the government projects, with its own labor camp, tractor (on loan), and storehouse. It had then a staff of seven: two surveyors, two carpenters, two cement block makers, and one "office boy" (Hogg, n.d., 92).

After UNDP/FAO support to the Isiolo cluster was terminated in 1980, Garfassa reverted to the control of its Committee. A locally recruited surveyor was found who is described as "officer-in-charge," but the supply canal has been silting up after each flood and scheme production has become at best intermittent. In 1982 the second chairman, who was from one of the minority groups in the area and had been a forceful opponent of the heavy government influence over the scheme, lost his place on the Committee. The Committee was reconstituted as a co-operative society, and a young man from the chief's group put in as Chairman. However, the drought of 1984 and the continuing siltation problems have brought scheme production nearly to a standstill. Hogg reports that about 40 percent of the scheme's registered adult males left to seek their fortunes elsewhere, and the remainder stay on mainly in hopes Garfassa might receive a new EEC funded gravity-fed canal.

We can take Garfassa to be, then, a locally initiated scheme which received a modest amount of external assistance (from the German Freedom from Hunger Campaign, food-for-work, and the Ministry of Agriculture) but which retained a substantial degree of autonomy. Its "success" has not been maintained. With the departure of a dynamic leader because of factional in-fighting, most of its initial membership and momentum have been dissipated. It illustrates how vulnerable such schemes are, both to internal factionalism and to environmental risks. Its modest performance would not merit comment were it not for the contrast to a nearby officially sponsored irrigation scheme at Malka Dakaa.

The Malka Dakaa Scheme is today much as it was described by Kortenhorst in 1983 (see Chapter Four).[1] The main supply canal is still incomplete, leaving the scheme's distribution system disappearing into weeds and thick dust. People living around and within the scheme suffer from cerebral malaria, which is especially virulent when it rains, and from hunger when it does not. The main source of cash other than scheme salaries (a sizable labor force remains on site) comes from retailing <u>miraa</u>, grown at some distance by Meru farmers in the Nyambeni hills. Those who can afford <u>miraa</u>--a powerful alkaloid--are said to forget their miseries. Most disturbing of all, from an engineering standpoint, is that the scheme's cement and tin offices are located high above the river where inevitably they will be destroyed as the river continues to undercut its banks.

Malka Dakaa was established in 1976, one of several UNDP/FAO assisted small-scale projects scattered over northern Kenya. Approximately 60 ha were developed, with less than one acre per family among those given plots. The water supply was by diesel pumps out of the nearby Ewaso Nyiro River, but the distribution system was laid out on a

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[1]Comments based on a site visit in early 1987.

very flat gradient (a fall of 1 meter in 1,000) rendering it subject to rapid siltation. A technician visiting in 1983 when the scheme was still operational warned that water losses from its unlined canals were high, and observed that the pumps were run only during government working hours so that the system dried out between each watering. Although the local Boran and Gabbra keep livestock, all the operations depended upon access to heavy equipment, free water, and food aid.

By 1979, the scheme had a population of about 2,000, but of the 360 registered members only 130 had received plots; the remainder were "harambee workers" receiving external food relief in return for joining the daily workforce. Some of those receiving plots had waited a year and a half or more as "harambee workers." There was an impressive managerial infrastructure, however: an FAO agronomist; five expatriate volunteers; two Kenyan managers (one for the scheme and one for the entire cluster); and numerous other mechanics, drivers, pump operators, surveyors, clerks, storekeepers and the like; as well as extension officers to deal with the tenants. The senior staff houses had electricity, piped water, and indoor plumbing. There was a well-equipped garage/workshop, a bulldozer, an earthscraper, four landrovers, and an 8 ton truck. All of this located down a 40 km bush track from the main road (Hogg, n.d., 51). However, three further events destroyed even the small progress which had been achieved in the first four years: the withdrawal of FAO/UNDP assistance; a major flood which destroyed the intakes for the pumping station; and a severe drought in early 1984 which drove nearly the whole population back onto famine relief.[1]

High Development Costs

The Malka Dakaa case helps correct the notion that operating on a small-scale necessarily brings lower costs and less formality within scheme implementation. de Patoul (in an unpublished 1985 FAO memorandum) documents a wide range in the unit costs for small African schemes. Some, such as rehabilitation of community systems in Malawi and Kenya (Kangocha in Nyeri) claim per ha costs as low as $100 to $250. More typically, others--such as Niger's small-scale irrigation or Kenya's Kibirigwi project--have costs of about $5,000 to $7,500 per hectare. Kortenhorst put Malka Dakaa's capital cost at $16,000 per ha, while Kuester and Wiggins (1982) put its overall per hectare development costs at above $30,000. Very remote schemes, such as those in Kenya's Turkana cluster, cost in excess of $60,000 per hectare. In Burkina Faso, three different schemes are shown to have costs of $4,000, $4,500 and $8,700 per hectares--about what the IBRD's larger formal schemes have cost in

When confronted with such a wide range in per hectare costs, it would be foolish to employ mean cost figures when defending small-scale irrigation as a general policy for intensifying African agricultural

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[1]Full details on Malka Dakaa are contained in Kuester and Wiggins (1982), supplemented by Hogg (n.d.) on sociological aspects.
similar environments within Mali.

production. What is more interesting is to investigate why schemes of similar size and complexity show such vastly different unit costs for their development and operation (here see Chapter Eight). Some of the estimates just reviewed count only actual construction costs for minor rehabilitation within already established systems--a common reason for very low figures quoted for assistance to "traditional" irrigation. Others may omit charges for the technical assistance component. In the Malka Dakaa instance, one can comprehend quite readily that to exclude the six expatriates, their houses and support from overall cost calculations could make a dramatic difference when appraising a small scheme. Still other estimates take as a given that projects effectively utilize all of the land targeted for development. What are we to make of instances like Malka Dakaa, where fields are used only for a few seasons before being abandoned? And, finally, the number of beneficiary households is sometimes quite small, so that even a modest scheme cost will become comparatively expensive when allocated on a per beneficiary basis.

More generally, Underhill has warned that where African governments deliberately foster small projects, there have been six common causes of failure in these state-aided systems (in Blackie et al., 1984:9):

- A lack of understanding by planners of what farmers really feel and want;
- The assumption farmers will become experienced managers without external assistance;
- The adoption of plans which assume higher levels of training, motivation and management than the civil service can actually supply;
- Underestimation of the foreign exchange requirements for inputs;
- A failure to draw upon farmers' own knowledge about climate, soil, water and crops; and
- A lack of genuine concern about project success, in part because project staff become the main beneficiaries.

Inappropriate System Architecture

Wensley and Walters (1985:22) argue that irrigation planners need to distinguish between poor technical design and inappropriate system architecture. System architecture should occur, in their view, "as an imaginative process of piecing together the various parts of a system by a multidisciplinary group including local farmers," whereas component design is generally a relatively straightforward technical task governed by standard engineering conventions (1985:21). They warn:

> Where systems fail to perform as intended, it is usually because of poor or no system architecture rather than poor

technical design. The quality control of component design (the stage following feasibility) may be quite good in terms of meeting accepted design standards but this is somewhat immaterial if, based on nontechnical factors, the chosen component is inappropriate. (Wensley and Walters, 1985:22.)

Probably they overstate their case in regard to sub-Saharan Africa: here (as Malka Dakaa illustrates) poor technical design is often apparent. Nevertheless, the larger point they are making is extremely important. A fundamental cause of the many problems evidenced in Africa's officially sponsored small-scale projects has been that the methodologies employed for their planning, construction, and operation are derived from system architecture suitable for large rather than small projects. As Wensley and Walters put it (1985:3): "In general, government assistance to small-scale projects appears to involve scaled-down versions of the same procedures used in the design of large-scale systems."

Anyone familiar with how large donors utilize the project cycle will recognize certain basic features shared by most large-scale development projects:

- definition of goals and objectives by the financing agency after consultation with national level officials;

- a proliferation of preliminary surveys and studies, undertaken typically by external consultants;

- highly specialized evaluate procedures applied in each field;

- local people regarded as objects for study and measurement;

- a phasing of financial investments to achieve the desired rate of return.

- most resources are concentrated on the initial, investment phases; and

- basic physical investments made early in a project predetermine many subsequent elements.

In short, this is what many observers call "top-down" or "blueprint" planning.

The resulting "system architecture" for project development has become highly standardized, and is widely taught in the accepted texts on project planning and management. Nevertheless, it is inappropriate for the kind of ongoing, evolutionary irrigation investment which successful small-scale systems often employ. Wensley and Walters contrast the conventional engineering design process with a more evolutionary approach which they urge should be adopted within small-scale irrigation. Taking their descriptors and adding some of our own (Moris, 1981), one can contrast how the two approaches differ in a number of key respects (Table 41). What clarifications does this typology offer in pinpointing why official small-scale projects have tended to perform so poorly?

One basic problem is that standard approaches lack any means for incorporating local expert knowledge. The expertise is assumed to reside within the external analyst, who requires data rather than insights from local practitioners. And yet the nature of small-scale irrigation is such that it must be intricately adjusted to local complexities which the outsider rarely understands fully. It would seem also that indigenous systems within Africa have tended to be adaptive, where as introduced technologies aim towards achieving a high degree of control through physical structures interposed within the local environment.

A second point of friction between the two approaches is in regard to how and where planners spend their time during the extended preparatory stages of project evolution. The highly specialized and detailed surveys required to feed into data intensive component designs can be very expensive when introduced into settings which lack organized data sets. The attention managers must devote to project appraisal comes at the very stage in the evolution of a project when otherwise they might be talking to potential beneficiaries and refining the project design (Moris, 1981:32-34). Specialized planners often object that evolutionary approaches are very slow to produce results. It is probably more accurate to say that they allocate their effort differently: detailed planning of structures may be left to mid-point in the evolution of a system, when it is made more reliable by expanding or changing certain key facilities. A "process learning" approach requires that much more time is spent in talking with local people before commitment to a project design occurs (Bagadion and Korten, 1985).

A third fundamental difference relates to the greatly reduced role of salaried staff within evolutionary, small-scale systems. In the planning and investment stages, small projects simply cannot afford the array of experts customarily employed in project preparation. They need a few hours at a stretch of judicious advice at various points as the joint activity evolves, quite possibly in response to unanticipated difficulties. Such inputs are hard to schedule in advance, since a given expert's salary costs must then be spread over many different projects to generate a reasonably consistent workload. This requires an entirely different approach to the provision of expert skills within project development.

Salaried staff are an even larger burden once small-scale projects become operational. Most locally initiated projects depend upon part-time or non-reimbursed assistance from skilled staff. Such non-market transfers based on reciprocity and recognition of common need are typical within many small enterprises. However, they are exceedingly difficult to arrange from a distance by outsiders, or in advance of the articulation of location demand. When a small-scale system loses its intake because of a flood, the whole system is put in jeopardy. However, it cannot afford to employ a full-time civil engineer to await this eventuality. As soon as small-scale projects begin to employ a nucleus of salaried staff, they must evolve internal taxing mechanisms to pay these costs as well as a turnover which can support the added load. On

TABLE 41

CONVENTIONAL VERSUS EVOLUTIONARY APPROACHES TO IRRIGATION DEVELOPMENT

Conventional Large-Scale Development	Evolutionary Small-Scale Development
Top-down approach	Bottom-up approach
May derive from a larger Master Plan	Evolves out of perceived local needs
Little predesign or pre-construction local involvement	Often intensive discussions and debates preceding commitment to project
Project selection by government and external donor	Activities not seen as constituting a development project
All major decisions made by government agencies	Major decision made by various interested parties
Data intensive design procedures	Minimal formal acquisition of planning data
Design done at distance by specialists	Design done in locality, by contractors
'Blueprint plan' arrived at to guide all implementation activities	No overall plan to guide implementation activities
Scheduled within fixed timeframe	Open-ended time frame for gradual development
Large initial investment in physical works	Major construction often midway in system evolution
Low initial utilization, rapid deterioration	High initial use of fairly modest physical works
Users expected to conform to planned layout	Users improve and adapt the system as they go
Facilities completed at outset and secure if properly used	Facilities subject to catastrophy such as loss of headworks or main canal
Physical reorganization of fields and farms often required	Minimal reorganization of fields and farms in gradual development of system

Source: Adapted from Wensley and Walter (1985), Moris (1981), and Moris et al. (1984).

Africa's small schemes (particularly those located in remote environments), farmers prefer to grow crops which increase household food security. If so, we can predict they will encounter severe difficulty in supporting a cadre of salaried staff to operate the technical aspects of their common production system. Government schemes, to the contrary, almost always start by engaging an array of occupational specialties which planners see as being necessary to carry out high volume agricultural projection.

A fourth difference concerns the degree and nature of farmers' participation in all aspects of project development. Analytically, one can distinguish at least 25 different aspects where farmers might share in project activities (Table 42). It is sometimes forgotten that large farmers in developed countries do control many aspects of their production, relying on agency expertise for only a narrow range of water supply functions. In Africa, instead, irrigation authorities have kept control over many of these aspects, leaving only the more onerous ones such as canal maintenance or field leveling to farmers.[1] Traditional irrigation by way of contrast leaves almost everything to farmers' own initiative, giving them maximum benefit from whatever improvements they choose to implement. In such circumstances, while outsiders may advise and encourage farmers to take certain actions, the outsiders control very little. Most African governments have in the past found this an unacceptable constraint if they were financing components within local irrigation systems (especially if their contributions were built under loan financing).

The somewhat pessimistic conclusion which can be drawn from this analysis is that merely "down-sizing" of standard approaches to fit small projects has not proven sufficient. African government departments and irrigation agencies do not yet know how to foster and support small-scale irrigation (Barnett, 1984). As Barnett notes, most of the literature on small schemes looks at technical and economic aspects from an external observers' perspective. There are few accounts that get to the roots of the social, organizational, and motivational aspects which we suggest are crucial for high irrigation performance. Two topics which are conspicuously missing in the huge literature on African irrigation are the role of local leadership and irrigation extension. Field interviews suggest that in communally managed irrigation, the support and initiative of an influential local leader is often a critical element responsible for the successful establishment of irrigation. Similarly, farmers obviously lack certain skills (both agronomic and organizational) required for successful irrigation, but receive no guidance at all from the extension service. There is a very strong case for instituting further exchanges of experience and insight between African countries like Senegal, Niger, Kenya, Tanzania and Zimbabwe which are developing new approaches to communally managed irrigation.

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[1]Here, see also Barnett's "Water Control Matrix" (1984:40) as a guide to deciding which water functions merit centralized control.

TABLE 42

POTENTIAL TYPES OF FARMER PARTICIPATION

1) Problem diagnosis
2) Project location
3) Field and channel layout
4) Land ownership
5) Financing of capital works
6) Construction of capital works
7) Ownership of roads and access rights
8) Selection of service agencies
9) Selection of enterprises
10) Decision on enterprise scale
11) Deciding on water rules
12) Determination of water delivery schedules
13) Resolution of disputes
14) Sharing of operating expenses
15) Sharing of input orders
16) Access to agency/scheme employment
17) Policing of members' obligations
18) Sharing of field equipment/operations
19) Sharing of storage/transport
20) Sharing of system maintenance
21) Access to profits (what share?)
22) Sharing of liabilities/risks
23) Sharing of environmental impacts
24) Degree of control over houseplots
25) Right to designate inheritance

Source: Moris, Thom and Norman, 1984, p. 24.

Guidelines for Small Projects

In summary, we have tried to distill what we have learned into a few rules-of-thumb for potential project designers and field staff. No individual guideline is applicable under all circumstances. We warn that experienced field engineers might give different advice on some points. Users of this report are urged to consult also valuable presentations of the Kenya experience by Kortenhorst (1983:28-51) and by Asmon, Njoroge and Wandurwa (1984).

1. Assume there will be existing right holders, seasonal as well as permanent. If all interested parties stand to gain something, a project is much more likely to succeed.

2. Do not proceed in locations where land or water rights are already contested.

3. Devote extra effort to securing a reliable water supply. Do not depend on small dams unless there is ample local experience to draw upon.

4. Check out hydrological estimates of high and low water levels by actual field interviews with farmers.

5. Use involvement of farmers at the planning and construction phases to create a pool of local skills and to compensate them for disruption of their own activities.

6. Anticipate training and assistance to farmers in doing field leveling.

7. Avoid unnecessary pumping. If pumps must be incorporated, choose them to take into account fluctuating water levels and available support services.

8. Never include "orphan" equipment which is not already supportable within the country and region.

9. Allow double the planned time for establishing the project if it has a major element of construction and is in a remote location.

10. Other things being equal, the project design with the lowest recurrent costs is to be preferred.

11. Avoid loan financing for infrastructural costs. Intensive preparatory work with farmers can often generate simple structures from their own resources.

12. Include subsistence security within irrigation plans, since this will be uppermost in farmers' minds.

13. Incorporate at least one high value "cash crop" to serve as an income generator in the initial years.

14. Pay particular attention to transport costs unless the project is already within a center of demand or will be part of an already operational marketing chain.

15. Make allowances for regular use of irrigation water by households and livestock during dry periods.

16. Assume farmers with only hand labor cannot cultivate more than about 1-2 hectares of irrigated cropland, maybe half a hectare per adult.

17. Assume that there will be competition for labor at peak periods and that labor costs will rise over time.

18. Involve local women in the planning and implementation of the project, and obtain their views on all organizational and procedural aspects.

19. Do not expect farmers to maintain structures at their own initiative if these are not located on their land.

20. Avoid plans for double-cycle cropping until farmers are experienced and a commercial input and marketing system has evolved.

21. Minimize paid employment and channel any employment opportunities toward the children of project participants.

22. Expect that cost recovery will be difficult and painful to all concerned. Recovery devices should be preplanned to coincide with times when farm families have access to ready cash.

23. If the scheme design assumes that either money or fuel must be kept within the community, be sure institutional arrangements for this purpose are already <u>effective</u>.

24. Locate the potential sources of health hazards and investigate the alternatives for minimizing them.

25. Avoid becoming a settlement agent. Keep it simple!

CHAPTER SEVEN

LAND TENURE ISSUES

Mary Tiffen[1]

Land Tenure in Africa

It is impossible to understand land tenure in relation to irrigation in isolation from generalized land tenure concepts. Unfortunately, it is very difficult to make exact statements except on the basis of localized investigation. Custom can only be synthesized with caution. To everything that follows, therefore, exceptions and variants can be found.

Customary Law

Customary law is still the basis on which the African farmer acts and decides his economic strategy. Two groups of customary tenure may be distinguished. On the one hand, there are various communal systems in which land is owned by a lineage or a village. Customarily, there was not outright sale, since the owners included the dead and the unborn. Usage rights are heritable, and can also be temporarily assigned, by pledge, lease or loan to another, including strangers. Usage rights may be reallocated yearly by lineage or village head or held for life. They may be held only by the household head or also by wives, children and dependents, depending on the farming system, and also on religion. (In Islamic areas women play less role in farming than in non-Islamic societies.) Rights are generally based on the claim of first clearance for cultivation; a lineage may control a large area over which ancestors cleared scattered, shifting fields. Consequently, descendants of more recent immigrants have less land, or hold by favor of the first claimants. However, this already reflects a situation of some population growth; in very lightly populated areas the original immigrants can simply clear (Tiffen, 1976). An element of flexibility is the ability to adopt strangers into the lineage/village, thus conferring equal rights to land (e.g., Chambers and Moris, 1973:55). A second group of customs derive from rights of conquest, and this is sometimes strengthened by reference to Islamic law on the rights of Moslem conquerors to take over pagan lands. In this case, a military ruler may have given out territory to his chiefs, whose descendants may still claim to be "maîtres des terres" with rights of allocation and control. Generally, however, these rights are exercised in a way that respects local inheritance customs. They are also modified by the low value of land in sparsely populated areas, and the need to encourage immigrants as clients, if a chief is to retain his influence. With the Mende of Sierra Leone (Little, 1951) and the Toucouleur of Senegal and Mauritania (Crosse, 1983) society may be

[1]Overseas Development Institute, London.

stratified into descendants of warriors and descendants of captives. While the powers of the elite group declined in colonial and post-colonial times, they sometimes still retain enough influence to manipulate land control at village level.

Changes in Custom

Group control can become so vague it is just the payment of a due or tax. In the northern states of Nigeria taxes paid by farmers to the "Native Authority"[1] were the direct replacements of dues in kind previously paid to emirs and chiefs. The British found it useful to conceive that they had, by conquest, taken over the rights of the Sultan of Sokoto as ultimate controller of the land. All land was therefore state land, on which farmers had customary rights of usufruct.

Even when there was not such a convenient Moslem doctrine to hand, colonization created the concept of State land, Crown land and Régime Domainial for unclaimed or "unused" land. Thus, colonial powers found it useful to emphasize the State's national control, often delegated through local authorities and local courts who could take account of "native law and custom." As Caponera (1979) said (in respect of water), the principal of "community interest" or "ownership" in land and water "may greatly facilitate legal and institutional measures for bringing all water resources under centralized state control." The principal also appealed to the socialist philosophy of many leaders of newly independent states. Agricultural officer were amongst the keenest advocates of retaining state control and preventing any move to a freehold-type tenure, in order to be able to enforce soil conservation and "good" farming methods and to prevent fragmentation and land speculation. Dumont, in his influential book False Start in Africa (1966 in English, 1962 in French) was much against freehold for "ignorant and lazy African peasants." Masefield (1952) reviews other reasons for limiting rights in land.

Political officers, more in touch with what was going on in native authority courts, more conscious of the dangers of riot and discontent stirred up by interference with land rights, were usually more cautious (Palmer-Jones, 1981). Already in 1952 Meek recognized and listed the social and economic forces, coming from population growth, the opportunities for commercial sales, the greater independence of young men, the smaller need for protection from chiefs and elders, which were leading, particularly in areas where land had become permanently farmed and commercial crops grown, to recognition of individual rights to particular fields, which included the right of outright sale. There are several references in the literature to African farmers having become *de facto* freeholders (e.g., in Meek, 1952 and Biebuyck, 1963) and the process was also being recognized in local authority courts. For example, in 1960 in Gombe, Northern Nigeria, the "native authority" recognized the right of sale of land which a man had himself cleared from bush. By 1970 the NA's chief judge recognized also the right to sell

[1]The local authority unit under the British régime.

land that had been inherited or bought (Tiffen, 1976). In countries like Kenya the prospect of individual registration of titles, which began in the 1950s, must affect even those areas still awaiting registration. The spread of Islam also has served to spread notions of individual tenure. In less densely populated areas land is still likely to be controlled according to older custom.

Customary Law on Improvements

It should be recognized, however that custom generally gives considerable protection to improvements. This was one reason why improvements--manuring, irrigation, etc., were not allowed on loaned or pledged land (Rowling, 1952). Rowling noted that in African eyes the man who plants or builds on land he is lawfully occupying owns the improvements. Even if he is ejected from the land and village, he has the right to reap his tree crops. Rowling went on to comment that this raised problems in ejecting a "settler" from a scheme or a crown tenant for failing to pay his rent; what to do about his house and trees. The African would think it inequitable he should lose these as well as his lease. In Mende society, by 1951, if people had cultivated a piece of land for 20 to 30 years, the owner would not be allowed to dispossess them without their agreement, and without providing at the same time, alternative land, and even houses (Little, 1951).

Moslem Inheritance Rules

Moslem laws on the inheritance are enshrined in the Sharia, and are therefore not susceptible to change by legislation. They are respected by all good Moslems. This is particularly so in long Islamized countries like the Sudan; in the Sahel and Savanna areas Moslem law is gradually affecting traditional custom. It prescribes land division with two shares for a son and one share for a daughter and a widow's portion. It applies both to land and improvements, e.g., trees, which can therefore be separately owned. As Islam recognizes private ownership of land by Moslems, this is another influence toward individualization (Adam, 1966; Crousse, 1983).

The Current Tension Between Governments and Farmers

The situation frequently is, therefore, that in the more densely populated areas the farmer has moved to a position where he feels the land belongs fully to him; while the politicians have moved to enshrine state control in new national legislation. Thus, we can get a consultant reporting in 1984: "Officially, all the land in the area is owned by the Government; smallholders claim to be owners of their land but in fact they only have a right of use of the land." They go on to recommend that the land become an estate. In densely populated areas, however, farmers are able to organize, or are sufficiently politically important, to enforce recognition of their rights of ownership, as has happened in Nigeria.

Where the state does promulgate new national laws, it is the educated and commercial classes who first realize the new opportunities. The concept that the land belongs to him who develops it--"mettre en valoir"--is enshrined in the 1980 Senegalese law, and gives rights to those with money to put in an irrigation pump (Mathieu, 1985). It can be at odds, therefore, with the socialist philosophy supposedly behind it.

Such national laws, Mathieu shows, tend to rigidify tenure. "Owners" refuse to lend or lease as easily as before, for fear of losing their land. Uncertainty is created over rights, but as Bromley (1982) has observed, predictability of rights, duties and obligations are necessary conditions for a dynamic society. As Coward has observed, it is particularly so in irrigation, where mangement and maintenance are linked to ownership (Coward, 1983).

Water Rights

Moslem Countries

The main sources are the FAO reports, ed. Caponera 1973 and 1978. The first volume reviews general Islamic thinking and that of different legal schools on water law, before giving individual country studies. The country studies continue in Volume two. Islamic law evolved in the arid countries of the Middle East. As Caponera states:

> In such areas, the land itself is of secondary importance, its only value being derived from its productivity which, in turn, depends on irrigation rights attached thereto. As water becomes scarcer, it becomes more essential to soil fertility and gradually develops into an object of ownership independent of the land . . .
>
> In this case, water becomes the main object of ownership. It is purchased, sold, allocated or constituted in <u>waqf</u> or <u>habous</u>, often along with, and sometimes independently <u>of, the land it</u> irrigates. (Caponera, 1973:29)

Some general principles common to all schools derive from agreed sayings of the Prophet; these include that high-lying areas should be irrigated before low-lying ones (leading to a frequent presumption that upstream owners may take water for irrigation, provided they return the surplus to the stream, regardless of the effect on downstream irrigators), that the quantity of water used should not exceed ankle depth; that ownership of canals, wells, etc., entails rights to a certain extent over neighboring land--there is a <u>harim</u> or protected area, within which rival works are not permitted (Caponera, 1973).

The importance of these precepts is that they are based on religion. Like the Moslem precepts for inheritance, they are not susceptible to change by national legislation. They may be ignored in practice, particularly in African countries where Islam is a recent introduction and original customs still prevail; but all strict Moslems will consider themselves bound by them, whatever man-made law may say. The "right of thirst," the duty to provide water to the thirsty (including, secondarily, animals), is also a religious precept.

The most Islamized of the countries here under survey are northern Sudan and Somalia, which also have the arid climate characteristic of the Middle East. However, Islam is influential in most Sahelian countries (covered in Caponera, 1978), and in the savanna areas to the south (not included in Caponera, 1978).

In a third report on other African countries, Caponera (1979) singles out one tradition that all waters are the common entitlement of the whole community. It is, however, quite clear from the earlier work that private ownership of water, apart from large rivers and lakes, is accepted (Caperona, 1973). The interpretation in the later work appears to reflect the author's desire for national control of water. Adam et al. (1971) explains how water charges on the private pump schemes in Sudan vary according to land cultivation rights and cropping patterns in a fashion very typical of the Middle East.

National Legislation

National legislation on water is summarized in Caponera (1973) for Somalia, Caponera (1978) for Chad, the Gambia, Mali, Mauritania, Niger, Senegal and Sudan, and Caponera (1979) for Benin, Burundi, Ethiopia, Gabon, Kenya, Mauritius, Sierra Leone, Swaziland, Burkina Faso and Zambia.

In most of the former French colonies, all waters belong to the public domain by law, except for wells and cisterns built by individiauls on their own land. However, it is noted that the population "frequently behave as owners of water and not just as users" (Mali, Niger, Senegal, Benin, Burkina Faso). In Gabon irrigation channels, etc. on private land are specifically private. In countries deriving their legal system from British common law, water in drains, reservoirs and underground is private so long as it is in the abstractor's possession. The right to use water is somewhat more extensive, particularly for owners of riparian land. The United States' "prior appropriation" doctrine giving priority to the first constructors does not apply in Africa. For many countries, water law is vague or leaves important gaps. The countries with the most comprehensive laws amongst those studied by Caponera were Sudan, Kenya, Mauritius and Zambia. Zimbabwe, not studied, is similar to Zambia.

In Sudan water rights attach to land. The Nile Water Use Control Board monitors quantity and controls pumping from the Nile, for which it issues licenses. These specify the season water can be used, size of intake, etc., and are automatically renewed every ten years. The pump owner, an individual, a cooperative or a government agency, takes 50 to 60 percent of the crop in payment (Barbour, 1972; Khider and Simpson, 1968). Well and hafir construction is subject to permission from the Rural Water and Development Corporation (Caponera, 1978).

In Zambia the Water Board grants water use rights, including rights for irrigation after investigation and subject to conditions, including respect of existing rights and to payment of compensation for any expenses incurred by a deprived party. There is no groundwater legislation. Swaziland revised its legislation, based on riparian rights, in 1967 (Caponera, 1978).

In Kenya the Water Act gives domestic users priority. The use of water for irrigation requires a permit. There is some control of groundwater abstraction and some juridical protection of rights of existing users, e.g., before draining a swamp (Caponera, 1979).

Some very large African countries such as Nigeria and Zimbabwe are not yet covered by the FAO review.

Customary Law and Local Authority Bylaws

Despite the note made concerning the individual countries cited in the previous section on the population behaving as if they owned water, Caponera (1979) states in his introduction that under existing African customary law, private ownership of water has remained generally unknown and individuals have only a right to use water. As already mentioned, this is a measure of his preference for State ownership of land and water. In fact, little work has been done on customary water rights. Meek noted the following as areas needing study: village rights over waterways, beaches and fishing grounds and the concept of village ownership of undeveloped land, including swamp land (in areas where village boundaries were fixed) (Meek, 1952).

What work has been done has been mainly in connection with pastoralists. This is mainly with regard to arid areas where it is likely that water supplies are too scarce for irrigation and will be mainly used for human and animal consumption. Generally, dams, hafirs, cisterns and wells belong to the person or group who have constructed them, or to particular villages. Sandford (1983) notes examples in Sudan and Ethiopia. He also notes the lack of information on rules for water management, control of access and on the location of authority. In Botswana, a government program gave District Councils the option of managing themselves new hafirs or dams constructed with Government aid, or of handing over responsibility to user groups. Here, dam groups assume direct management, though formal handovers were rare (Fortmann and Roe, 1981). As a working hypothesis, it seems reasonable to assume that pastoral groups in arid areas will consider themselves to have ownership and management rights over their constructions.

In Machakos District, Kenya the County Council derived revenue from a cess on lorries removing sand from the river bed, and were upset over lack of consultation by the central government's aided Machakos Integrated Rural Development Project. The latter failed to consult the County Council in its water development plans, which would have banned sand extraction. This is indicative of a conflict of jurisdiction over river beds, which could also affect irrigation (Tiffen, 1985).

In regard to canal constructon, few indigenous schemes have yet been studied. Gray studied the Sonjo system in operation in Tanzania in the 1950s, a considerable time after construction. Ultimate control belonged to 17 hereditary elders who had priority rights (Gray, 1963). This system is no longer operating. In the Marakwet system in Kenya the furrows belong to the clans or lineages constructing them; individuals have water rights attached to their land rights. Some "modern" trading, health or educational institutions have tapped the furrows for piped water, arousing little or no opposition. But there is potential conflict if their demands grow (Ssenyonga, 1981).

Main Issues Arising

Many African countries have no legislation or juridical principles on areas central to good water resource planning and irrigation planning.

Priority Between Uses--Human, Especially Urban Needs Versus Agricultural or Livestock Needs. This is an issue that is vital to river basin planning. Yet it is not, apparently, among the tasks given to the River Basin Development Authorities (RBDA) in the Nigerian Act establishing them in 1979 (Griffith, 1982, lists their main duties). Their tasks are to develop water resources for multi-purpose use, provide water for irrigation and urban supply, but not establish priorities, monitor use, or ration water. As a consequence, a RBDA can commission studies for farming use of water, while a State Water Corporation concludes all the water is likely to be needed for domestic and industrial use (Siann, 1980). The Marakwet example cited above shows that a similar conflict could arise in Kenya. (Nigerian legislation on River Basin Authorities and land tenure is now changing--West Africa, 14 May 1984:1009). A similar possible conflict between urban and agricultural needs is noted in Burkina Faso (D'At de St. Foulc, 1985).

Irrigation Priorities. Only a few countries have established systems for monitoring existing irrigation uses, and establishing priority rights as between upstream/downstream irrigators; first in time, later in time users, etc. A textbook on irrigation planning using the Usangu Plains of Tanzania as an example notes the existence of furrows already constructed by farmers. It is probable the farmers concerned feel they own these improvements. The book considers a project for higher technology irrigation for State and cooperative farms without discussion as to whether the furrow constructors have prior water rights, or indeed any rights whatsoever: for instance, rights to consultation or compensation when their water is diverted (Hazelwood and Livingstone, 1982). The rights of existing users of water from floods or groundwater which may be modified by dam construction are also neither monitored nor protected, although they can suffer substantial loss (Adams, W.M., 1983; Stock, 1977). Farmers in northern Nigeria are currently making substantial investments in wells and pumps which may be nullified if groundwater regimes are altered by government schemes upstream (Chapman, 1984).

Monitoring and Licensing Systems. Few countries have these, either for groundwater extraction or river water extraction.

It has been said that predictability of rights, duties and obligations are necessary conditions for dynamic society (Bromley, 1982). Without predictability, farmers cannot make sensible plans for their economic strategy, nor will they be encouraged to invest. Generally speaking, legal predictability is lacking in sub-Saharan Africa.

Tenure and Management in Farmer-Initiated Systems

Irrigation's place in the spatial context and in the historical development process is well considered in Ruthenberg (1980). Full irrigation sytems, and farms which are entirely irrigated, have not yet generally been found sufficiently worthwhile for farmers to initiate themselves in Africa except in certain special circumstances. Partial control systems are more typical.

Partial Control Systems

Partial control systems are those where either the inflow or the outflow of water is regulated or partially regulated by human constructions, but where there is no full control over quantity and timing of both flows. One is concerned here with flood recession land, swamps, polders and valley bottoms (wetlands).

The value of such land-use depends on two factors: rainfall and marketing opportunities. Where consumption crops can be grown by extensive methods on rainfed land, this is preferred as less labor-demanding, and the swamps, valley bottoms, riverine lands, etc., are used mainly for dry season grazing. It seems generally accepted that if local villagers do decide to cultivate these lands, in accordance with customary law, their right to do so takes precedence over users of the land for grazing. Conflicts can arise if the land is not cultivable by means within local resources, and the government takes it over for state purposes; likewise, if a chief sells village rights, without consulting other villagers, to outsiders who use mechanical tillage, drain swamps, etc., as in Ghana (Goody, 1980; Konings, 1981). It is only in exceptional political circumstances that pastoralists are able to get some recognition of their rights, e.g., the Afar in Ethiopia (Beshah and Harbeson, 1978; Simpson, 1976; Emmanuel, 1975; Harbeson, 1975).

When wetlands are near a lucrative market, they may be developed for high value crops such as sugarcane or vegetables, while rainfed lands are used for cereals, etc. In this case their sale or rent value is higher than that of rainfed land (Turner, 1977, for northern Nigeria).

Where rainfall is unreliable or inadequate, a plot of wet land is valued. If markets are not available and population is sparse, a small area only is needed for consumption, and the land has no cash value.

Here, however, customary controls by lineage heads, maîtres des terres, etc., are manipulated to ensure priority access as against "strangers" or politically less powerful groups (many examples in the literature from Senegal). In very arid areas this land has a high value and may be individually held and commercialized, as in the Sudan (Dafalla, 1975). In the Jamu'ija area government attempts to nationalize this land were resisted with violence (Shepherd, 1980). Such land has been developed in the past under a variety of tenure systems. Only a few of those mentioned in the literature will be singled out here. The traditional polders in Lake Chad seem to have been constructed by corvée labor under the local chief's direction. The workers were later rewarded by a plot. Later government developments went in advance of demand, so labor had to be paid with Food Aid. The rights already acquired by villagers came into conflict with the requirements of development projects (Bouquet, 1985). Linacres (1981) found different types of tenure among Diola cultivating swamp and valley bottoms in Senegal. In one case, a large dike was constructed collectively, but each section was maintained by those now owning the adjacent field, with collective responsibility only for a key danger point. The fields were worked jointly by husbands and wives, with tenure and inheritance going by the male line. In an inland swamp area, owned by descendants of the original three families developing it, the swamp plot was often worked by a woman lent the land by brothers and uncles and passing the land to her children. It is common for women to have rights in swamps in The Gambia and Sierra Leone, also (e.g., Dey, 1980). In Burkina Faso Mossi lineage heads manage the bas-fond lands. While lineage members can plant trees, for non-lineage members the loan of a plot specifically excludes use for trees. The lineage enforced its control much more strictly on bas-fond land than on uplands (Lahuec, 1970).

In Madagascar, the oldest immigrants, developing a valley bottom for rice cultivation, became its owners. Late arrivals became sharecropers or from 1931, bought the developed plot. The upper slopes were collectively owned and used for pasture; the lower slopes were individually owned. However, sales, leases and sharecropping occurred only in the valuable rice lands. It is not clear who owned and maintained the irrigation channels (Marchal, 1970).

In the Hadejia Valley, Nigeria Sokoto immigrants took up land in the flodplain, bringing with them their techniques of channel construction and floating rice varieties to make effective use of the annual flood (Stock, 1977).

In all systems noted, the wetland plot is only part of the family's total activities. It is invariably combined with either or both wet season cultivation of uplands, and livestock rearing (many literature references; summary in Kortenhorst, 1980).

Full Control Systems

One can distinguish three main types.

Individually Owned Systems. These are quite common in West Africa, probably covering more hectares in total than large-scale schemes in many countries, but have not been much studied, particularly in their tenure aspects. The main technology is the lever device, the shaduf, which enables a man to irrigate about 0.1 hectare. Normally, this is on his own land, and this may be either fully in his own control, with sales, cash leases, etc. in densely populated areas (Ega, 1984), or subject to attempted control by village heads (exacting payment of dues) in the case of newly developed lands in less populated areas. Recently, farmers have been investing in small pumps and wells to replace the shaduf, enabling them to farm more land. In some cases they have come to various arrangements for payment by others for the use of water or land which the owner is unable or unwilling to manage directly himself. For many years farmers owning small wet season farms in the densely populated Kano zone have migrated in the dry season to cultivate vegetables on irrigated plots they acquire on temporary loans or leases in suitable villages (Tiffen, 1984). While such migration may be less common elsewhere, the use of the shaduf, and its substitution by the pump, also occurs in Niger, Burkina Faso and Mali (FAO, 1983). There is often a preference for individual ownership. In Mali, when USAID proposed four associate owners per pump, farmers were opposed and a single owner per pump was agreed upon (Moris, 1984).

Capitalist Systems. By capitalist systems, is meant irrigation covering a larger area than the normal area that an African farmer manages on his own, and where workers, sharecroppers or tenants are used for part or all of production. Such systems have long been known in the Middle East, and Gaitskell (1959) records the division between suppliers of capital (water wheel, cattle) land and labor in the Gezira area early in the century. In the 1950s there was a boom in private pump schemes in the Sudan, when cotton prices were high and a pump investment could recover costs in three years. Leading families and politicians were among the investors (Barbour, 1972). The fall in cotton prices, and the rise in fuel prices and difficulties in obtaining fuel, have since affected profitability.

In the 1960s many of these schemes were officially converted into cooperatives, a change that was often only nominal, with 50 percent of crops being paid over for expenses, and the surplus, if any, much at the disposal of the officers (Khider and Simpson, 1968). On some schemes there has been pressure for water rates paid in cash, but members who hold land as tenants still pay by sharecrop. Fruit, vegetable and fodder producers pay cash (Adam, 1971). In Nigeria, at least some farmers have invested in large pumps and large farms, but no details on tenure arrangements are available.

In Zimbabwe some white farmers, as individuals or as syndicates, obtained grants of low veldt land and established irrigated estates for sugar, citrus and beef, from the 1920s onward. Certainly in the 1950s these were government-aided; the State paying the cost of constructing dams, canals and communications, and the irrigators paying for the internal water distribution system, clearing and leveling, housing and other facilities. They appear to have been profitable (Pollock, 1968).

There are also medium-sized private commercial farmers who have constructed their own dams and weirs, with or without assistance from the Agricultural Finance Corporation. Like the large estates, they are generally efficiently run (Mupawose, 1984). There are known to be other commercial estates elsewhere in Africa, but literature on these has not been found. In Kenya at the end of 1978 there were 10,000 irrigated hectares in the public sector, 15,000 in the private sector and 800 in the communal, and it was the private sector that was expanding most rapidly. However, Toksoz (1981) gives no details.

Communal or Cooperative Systems. These are systems in which control and ownership of the irrigation works are located in a corporate body, either traditional or modern. As already mentioned, the furrow systems of East Africa appear to derive their corporate control from clan or village institutions. This is also the case in the Taita Hills system, Kenya, recently observed by Fleuret (1984). In the Anlo system in Ghana, which combines communal flood control and regulatory works and privately dug wells for supplementary irrigation, the land is held by 15 clans. Planting dates for the shallots are chosen by community leaders, usually large farmers, to prevent the spread of pests. Land distribution is uneven, with some individuals having a thousand beds, others less than 10, deriving both from usufructuary rights at the time of settlement, and inheritance patterns. However, there are many ways by which young men can enter the system or by which those with too much land to manage effectively can pass it to others--by short-term fixed rents, longer term sharecropping arrangements, mortgage/pledge arrangements; seed and land sharing arrangements, etc., and even sales (Chisholm, 1983; Grove et al., 1983).

In at least one Senegalese village having a tradition of some communal fields, local people, led by a returning migrant aspiring to develop his village, wanted to organize a cooperative irrigation scheme with the help of a French technician, using indigenous institutions. In this case their plans were frustrated by SAED, which had a preconceived development program (Adams, 1981). In other cases educated and enterprising members of a community have been able to organize a western style cooperative (Khider and Simpson, 1968, regarding a New Halfa vegetable coop). D'At de Saint Foulc (1985) describes how some Burkina Faso peasants, abandoning an official scheme for green beans, set up, as individuals or small groups, their own irrigated gardens with small pumps and later accepted a French volunteer's help in organizing a cooperative for marketing functions only.

Some Characteristics of Farmer-Initiated Schemes

The most characteristic type of full control system in Africa is a small, individually owned plot, with individually owned irrigation equipment. In partial or full control systems involving communal efforts to construct works, control of the land, farming processes and output is typically in the hands of individual families even if land allocation and some regulatory functions are carried out by lineage heads, chiefs, elders, etc. If marketing is cooperative, which is exceptional, the cooperative seems to be usually more under farmer control than in the normal government-designed cooperatives. Normally, however, farmers market their own crops and many systems are obviously very much adjusted to market requirements. Holding size is usually variable as between families, and adjustable by various loaning, renting, pledging or selling mechanisms. There are a few exceptions to this in the Sudan, where the Gezira model is all pervasive. There, at least one farmer's cooperative also held land as a cooperative and divided it equally among members, who then made their own crop choices and cultural plans (Briggs, 1983). The ownership of the protective works, channels, etc. is more likely to be collective, though sometimes arrangements are made to give maintenance responsibilities to adjacent land holders. Communal work and responsibiity tends to be restricted to the essential minimum. The schemes are necessarily run on lines that are profitable to the owners, covering their costs and producing either for the market or for local consumption, as appropriate. It is particularly noticeable that in isolated, lightly populated areas plot size is small, producing simply for family needs. Operators have been known to reject, correctly, expensive cash inputs of tractor services, etc., which might raise output, but for which an adequate cash return could not be achieved (de Wilde, 1967, regarding the Marakwet system). It is also noticeable that the labor-intensive small plot is often only part of a farming system which includes less costly rainfed farming, particularly for low value cereals, livestock raising, etc.

Issues for Consideration

Issues which require further research involve the rights and productivity of flood recession land users and groundwater users, particularly when these may be affected by dams for irrigation schemes; the whole area of small swamp, fadama, or dambo development (wet lands) and whether this should not be left mainly to private and/or local village initiative; whether the rights of constructors of partial systems or low technology systems should be respected; the links between marketing, size of plot and technology used; the economics of farming systems in which irrigation is a partial element, and is combined with rainfed farming, and livestock raising, etc. In schemes where communal activity has created dams, canals, and other structures, there is a need for a clear definition of the ownership and control of these assets, for an agreement among those concerned about the division of water and for clarity over the tenurial status of the irrigated land, but there is little literature.

It is noticeable that there is almost no literature on large private irrigation, nor on semi-commercial, semi-state estates, such as those initiated by the Commonwealth Development Corporation. In the latter case, there is more literature on the relatively small outgrower element at Vuvulane, Swaziland (Tuckett, 1977; Cobban, 1981) than on the nucleus estate. There are many examples of sugar plantations on this kind of model, whose success has varied with the price of sugar. In some cases they have been taken over by Government and have continued on efficient lines (informal talks with CDC officials). There is also the rather similar example of the SEMRY rice production unit in north Cameroon (Buchmann, 1985). A significant comment on the Gezira is that "early commercial management . . . was responsible for the satisfactory attitude towards cost control . . . which has not been easy to achieve elsewhere" (El Hadari, 1972).

Tenure Issues Arising During Planning and Implementation

At the planning and implementation stage it is necessary to establish the existing situation in regard to land use, productivity and rights and the number of people involved, in order to calculate benefits and costs in the with/without project situation, to make adequate arrangements for those who may be displaced, and to plan, in the light of the needs, resources and rights of the people concerned, physical and organizational arrangements for the new scheme. This may entail making decisions on housing provision, settlement layout, selection of irrigators and size of irrigated plot. It is not always easy to know how this was done, since the relevant documents are usually confidential feasibility studies. Reports after the event make it clear that the necessary investigations have often either not been made, or not thoroughly made. The result has been unanticipated costs, unanticipated loss of production, particularly off-scheme, unanticipated lack of commitment by the irrigators, who have other interests, displacement of people who have often quit farming and suffered much hardship, and the hostility of those who were supposed to benefit. In the few schemes where proper investigations were made and taken into account, the initial years of the scheme seem to have been relatively trouble-free. Problems have been particularly acute in schemes that have involved considerable displacement of the population.

We will therefore look first at schemes where either the existing population can be accommodated on the new scheme or where the development is in nearly "empty" lands currently only seasonally used by pastoralists, or with only scattered rainfed farms. We will then look at schemes for areas already intensely farmed where considerable numbers have been displaced, temporarily or permanently, by reservoirs, headquarters sites, construction activities, etc. The issues raised by faulty or inadequate investigations at the feasibility stage will then be considered.

In many cases it is decided to have what is known in Africa as a settlement scheme. This involves taking further decisions on tenant selection criteria, tenancy size and housing and village provision. The criteria used for these decisions will be examined. The justification of the settlement model and its management implications will be reviewed in the next section.

Investigations in Schemes Not Planned to Involve Displacement

The investigations into land tenure in the Gezira are described in Gaitskell (1959), Miskin (1953), Khalil (1970), and Salam (1979). The assumption that land was state owned was soon proved wrong (Khalil, 1970) and many owners produced written title deeds (Gaitskell, 1959). The process of registering rights was not simple, due to Moslem inheritance rules (Miskin, 1953). It is clear that trouble was taken to ensure general consent, to avoid political difficulty.

The pilot demonstration projects had an important role in this, preceding the main scheme by several years (Tiffen, 1984). The land was leased at its highest rainfed value for 40 years; much was bought by Government during the 1930's depression or later (Salam, 1979; Khalil, 1970). Khalil raises the issue as to whether leasing is an appropriate strategy for a national government, as opposed to an expatriate agency anxious to avoid conflict. Allocation of tenancies was done with and through the owners, and appears to have gone smoothly, so production acivities started on time. The cropping pattern allowed for the desire to continue sorghum and livestock production.

The Gezira has in many ways been the model for subsequent Sudanese schemes, although the elements of pilot projects and of consideration for existing activities have tended to be neglected. In later schemes it has generally been thought sufficient to record rights and to offer compensation for loss of grazing and rainfed farms by offering priority access to tenancies on the scheme. This has been continued after the nationalization of land in 1970 (Benedict, 1982; Ebrahim, 1983). The consequence is that the farmers concerned feel they have a moral right to their tenancies, although these are theoretically renewable annually. Owing to disputes about terms, neither the existing semi-nomadic farmers nor the displaced Nubians on the Khasm el Girba/New Halfa scheme had by 1979 signed their tenancy agreements. However, when the management tried to evict poor performers, protests were so strong that they or relatives got the land back (Pearson, 1980).

Main problems arising on this and similar schemes such as Rahad have been due to the failure to allow for continued interest in livestock, and the fact that settlers still have access to rainfed land for sorghum off the scheme. The Gezira has been exceptional in incorporating even a small fodder crop component. Consequently, settlers have generally maintained off-scheme interests, giving less than the optimum labor input to their tenancy, or appointing sharecropping managers to look after the less profitable irrigated tenancy (Benedict, 1982; Ebrahim, 1983; Heinritz, 1972; Hoyle, 1977; Pearson, 1980; Sorbo, 1977). Similar failures to realize that settlers who previously lived in the area may retain rainfed land and will continue to own livestock, both of which they will take into consideration in planning their labor allocations, have been reported from many parts of Africa, east, south and west (e.g., Kortenhorst, 1983 for Kenya; Hartog, 1979 for Burkina Faso).

Schemes Involving Displacement of Existing Farmers

The difficulties, costs and stresses of resettlement of populations displaced by large reservoirs have been extremely well documented (Brokensha and Scudder, 1968; Scudder, 1973 and 1975; Chambers, 1970).

The demanding preparatory work, including identification of the rights and numbers of those entitled to compensation, and arrangements for their new accommodation and economic livelihood, has been detailed by Butcher (1971) and described by an administrator responsible for the evacuation of the Sudanese Nubians (Dafalla, 1975).

The Nubians displaced by the Nasr Reservoir had a certain political importance. The Sudanese government also received compensation from the Egyptian government, so money was available to treat them as fairly as possible. Their rights, down to the last fraction of a date palm, were recorded and compensated. The local village and district authorities were involved in the planning (Dafalla, 1975). They regarded their new tenancies New Halfa as compensation for disturbance, and insisted on also receiving double the quantity of freehold land that they had previously had, although this dislocated original plans for the division of the irrigated land (Heinritz, 1972). New Halfa had problems due to the Nubians' propensity to maintain their non-agricultural work interests, which have been more lucrative than farming, but at least a difficult operation passed off peaceably.

Available literature on resettlement does not seem to have been fully considered by the planners responsible for the recent large schemes in northern Nigeria. The main issues involved are:

- Land use and rights by those outside the project area who will be affected by changes in water availability;

- Ownership of land and issues of compensation within areas that will be needed for reservoirs, headquarters, etc.;

- Compensation for disturbance for farmers losing income while construction activities take place on their land; and

- Ownership of land within the project areas, and any necessary rearrangements of holdings subsequent to development.

The position has been complicated by differences of view among the farmers concerned and Federal authorities (the River Basin Development Authorities - RBDAs) on whether land was individually owned. The RBDAs view was enshrined in the 1978 Land Use Act, which asserted ultimate government ownership and gave State governors the right to revoke "customary rights" and to grant leases, after compensation for standing crops and improvements. The farmers, and local politicians and entrepreneurs, knew that tenure had evolved toward something close to freehold, and that land was commonly bought and sold in the belief that such transactions conferred permanent rights (Wallace, 1981; Bird, 1984).

In the case of the Kano scheme, the Dutch consultants originally recommended that the Government buy in the project land and treat it as a settlement scheme. In a heavily occupied area this would have been both expensive and unpopular and it was agreed the farmers concerned should receive their land back less 10 percent. It is not clear if they were compensated for disturbance during construction. The disruption left many disadvantaged families, while giving opportunities to land speculators from the towns (Wallace, 1981). The high-handed treatment of the farmers, failure to convey to them information on, e.g., the costs of the irrigation works provided, and the feeling that influential persons were able to gain advantages during the reallocation, have caused continued disgruntlement, although those who received back their land seemed by 1982 at least not to be worse off than before, if promised management services were delivered (Roy, 1983). Farmers displaced by the reservoir or scheme works received either poor quality land in new villages or monetary compensation. This was eventually raised from Naira 80 to Naira 250 per acre, an unforeseen cost which was still generally insufficient to enable them to buy replacement land (Wallace, 1980).

In the Bakolori operation farmers were supposed to, but did not, receive compensation for seasons when they could not farm due to construction works. This issue, plus the issue of compensation (also delayed) for those who lost land outright, led to physical obstruction organized by farmers and their traditional village leaders, close together physically and socially. This had to be quelled by military methods. At the cost of many deaths, they finally received monetary compensation. After construction the farmers were supposed to be reallocated their own land; this proved so difficult when landmarks had been destroyed that the task had to be handed over to traditional leaders, who eventually got some farming restarted (Bird, 1984).

The Dadin Kowa Dam is now filling up a large area previously densely farmed. Here lessons have been learned, rights and boundaries have been mapped, people and their local authority leaders have been consulted over resettlement wishes and compensation, with difficulty, has been paid. One problem has been that one of the States involved pays compensation for land itself, as this has long been legally sold (Tiffen, 1976), while the others pay only for improvements (Bird, 1984; Griffith, 1982).

There is no evidence in the literature that the cost-benefit analysis of these large-scale Nigerian schemes took proper account of the with/without project situation. In most cases the land flooded by the reservoir was already farmed one season, and was large in proportion to the area developed for irrigation. Further, the dams for both Bakolori and Kano are known to have damaged or halted cultivation of rice and vegetables on flood recession land and valley bottoms downstream. Because of failure to consider land use outside the project area, more production may have been lost than gained (Stock, 1977; Adams, 1983).

Issues Needing Attention at Feasibility Stage

Several important issues are involved as follows.

1. The need to consider land use in the with/without project situation, taking into account down-river effects and the reservoir area. Ruthenburg (1980) queries the economics of some Asian tank schemes with ratios of reservoir to irrigated area of 1:4. The Nigerian schemes quoted above have far lower

ratios, e.g., Kano, 58,000 acres irrigated from the Tiga Reservoir, covering 44,000 acres (Wallace, 1981).

2. Is it politically possible to ignore a situation in which people for many years have acted as if they owned land, bought and sold it, believed securely in their rights to pass it to their heirs, etc., on the grounds that traditionally the local rule "owned" it and the peasant has only usufructuary rights? As a President of a Rural Council said in Senegal: "Au Fouta, il y a la loi sur la domaine nationale, mais il y a aussi les faits" (Mathieu, 1983). In Nigeria local realities had to be recognized, at the cost of unexpectedly high levels of compensation. It is never enough in feasibility studies to accept the assurances of central governments on the state's legal rights without also ascertaining on the ground local views, though there are obvious diplomatic difficulties.

3. It is necessary to incorporate provision for compensation and the cost of resettlement in the initial economic and financial plan. This is often not done, either because it may adversely affect the calculations on economic viability, or because it is felt to be the responsibility of the national government. As a result, money is simply not available, or arrives in very delayed fashion, for farmers who are in immediate need because they have lost their livelihood (Bird, 1984).

4. There are rarely either up-to-date population figures or cadastral maps. Time must be allowed during the planning stage for the collection of this information if resettlement is to go smoothly. The collection of these data can be quite expensive if it means special surveys by expatriate consultancy companies, though it can be done efficiently in some countries by local administrators working with the local authorities (as in Sudan).

5. It is necessary to consider if the population to farm the irrigated area will retain land and assets off-scheme which may affect labor availability.

6. Pastoralists' rights have usually either not been compensated, or compensated by the offer of a tenancy. Only occasionally, as in the case of Afars, are the nomads in a political situation at least to get discussion of other forms of compensation (Harbeson, 1975). However, small monetary payments for loss of grazing rights to schemes taking over land for state or commercial farms have been made in Senegal (Mathieu, 1983).

Settlement Scheme Planning

The typical African irrigation scheme has been modeled on the Gezira, with annual, standard-sized tenancies. Having either bought out or ignored local rights, it then becomes necessary to make decisions on tenancy selection criteria, tenancy size and housing and infrastructure provision.

Tenancy Selection Criteria. Tenant selection in the Sudan is normally, as we have seen, done by giving priority to owners of land and grazing rights, provided they meet certain conditions on age, willingness to work the tenancy, etc. Large landowners can register more than one tenancy under the names of dependants and relatives. Next come local landless laborers with agricultural experience. Outsiders may be offered any remaining holdings. Selection is done in cooperation with leading sheikhs and local authorities. The main exception has been Khasm el Girba (New Halfa) where the displaced Nubians were given tenancies as compensation regardless of the usual conditions (Adam, 1971; Benedict, 1982; Gaitskell, 1959; Khalil, 1970; Pearson, 1980; Salam, 1979; Taha, 1975; and others). Once landowners nominate a relative or landless laborer to a tenancy, the person concerned should receive a legal contract with the irrigating authority, which reduces his former social dependence, and substitutes dependence on the management (Gaitskell, 1959; Salam, 1979; Barnett, 1977; Beer, 1953). Village Production Councils have a voice in the selection of new tenants (Beer, 1953).

In Kenya most schemes, particularly those managed by the National Irrigation Board, are intended to select tenants from the landless, so easing population pressure on overcrowded quality rainfed land (ILO, 1972; Chambers and Moris, 1973; Fitter, 1983). South Kano is exceptional in that it was planned to provide for those with existing land rights. As already noted, early schemes were set up to cater for Mau Mau detainees, particularly Kikuyu, settling them in non-Kikuyu land. Since 1960 new tenants have come from the local district. Clan elders select them, supposedly on the basis of landlessness and joblessness. They are recommended to select married men aged 35 to 40 (Veen in Chambers and Moris, 1973). Many of the small schemes set up by voluntary agencies cater especially for cattle owners destituted by drought, who live in adjacent areas (Hillmann, 1980; Kortenhorst, 1983; Brown, 1980). Often the main requirement is destitution--difficult to prove or quantify.

The very large Office du Niger scheme, in a very sparsely populated area, has never been able to be selective on tenants. Originally they were recruited from the whole of francophone West Africa, often using compulsion. After 1945 compulsion was withdrawn, and many departed between 1950 and 1963 (de Wilde, 1967; Zahan, 1963). Since independence, settlers have been Mali nationals. There is little information on criteria for selection on most large schemes in francophone Africa. In Kou, Burkina Faso, migration was incited by broadcasts, and achieved 940 families between 1967 and 1978. These took up all the irrigable land (it was originally designed for 1,200 families, but some land was lost by poor drainage). The immigrants, mainly Mossi, were supposed to have four active workers per family; this condition had to be waived for the 250 families originally living in the area. Even so, there is a fluctuating participation of less than 100 of these families, as they have other interests (Ouedrago, 1979; Hartog, 1979). In Niger the order of priority is: (1) original occupants of the land; (2) professional farmers; and

(3) traders, officials, etc. (Cissé, 1985).

On most large schemes in anglophone countries, the tenancy size is standardized. Equity of income distribution may be the objective. The size varies from 0.1 hectare to several hectares, and is given in most of the literature on the schemes. It may be determined by calculating the area necessary to yield, from a fixed cropping pattern, an income sufficient to stop urban drift. Alternatively, it is planned to be workable by the family without resorting to hired labor. In either case, it is normally assumed the families have no off-scheme interests. Zimbabwe is an exception, with some vegetable micro-plots intended to supplement other activities (Makadho, 1984). The large Gezira holding was planned to incorporate fallow, for reasons of fertility and crop hygiene, as water rather than land was the scarce factor. Most later schemes have assumed mechanization, because of labor shortage, so holding size has remained relatively large. The literature shows that planners have frequently over-estimated income levels and under-estimated labor requirements and the willingness/availability of all family members for farm work. Not much has been found on criteria for holding size in francophone countries. There does, however, seem to be more provision for size to vary according to family labor capacity (de Wilde, 1976, re Office du Niger, Mali; Moris, Thom and Norman, 1984, re ONAHA schemes in Niger).

Provisions of Housing and Village Amenities. This is not always necessary. In the first phase of the Gezira, the population remained in existing villages, canals taking slight detours if need be. However, quite frequently housing has been built for tenants, or tenants have been given loans to build houses. This immediately raises the issue of the ownership of the house if the tenant is on a yearly lease subject to eviction for bad cultivation. As we have seen, almost all African customary law recognizes a man's right to his "improvements," and the possible conflict with settlement disciplinary policy was raised by Rowling (1952), but not faced.

In the Sudan the minimum has normally been done. Existing villages, if any, have usually been incorporated, and additional ones laid out with plots. The displaced Wadi Halfans got some village amenities and two-room concrete houses. They found the latter overcrowded, but the design did not make it easy to add rooms (Heinritz, 1972). In the same area the nomad tenants got no housing or services, only some timber for construction (Pearson, 1980). On the Rahad, village areas were laid out and landless laborers and nomads were given a plot and a small grant (LS 50) to build a house. The planners tried to reflect the original social groupings in the villages, but it was not always possible (Benedict, 1982).

In the Office du Niger the tenant received housing and equipment on credit; it was originally envisaged he would receive a permanent occupation permit after ten years, but instead the land was nationalized (de Wilde, 1967). The cultivation right is transferrable by inheritance, but many settlers in fact leave after some years, abandoning their houses. In planning settlements the Office tried to group settlers by tribe (Zahan, 1963). In Kou, Burkina Faso a badly built house of 8.4 x 3.5 meters was provided for the typical family of 8.5, leading to overcrowding (Ouedraogo, 1979).

In Kenya, Mwea was conceived as a piece of social engineering. Clans were deliberately mixed in the villages, which created some social problems. Until 1964 housing was provided. After 1964 there was a system of loans repayable in three years, whereby a better standard house was built for the tenant. In 1970 the terms, and the house, were improved, but people off-scheme could get longer term loans for their own designs (Chambers and Moris, 1973).

On Ahero housing was built for all tenants, incorporating the existing villages (Boodhoo and Fuller, 1981). However, many of the new settlers were not accustomed to living in concentrated settlements and resented all the rules and regulations. Over time they opportunistically reorganized the houses, spacing them further apart, using indigenous material, growing vegetables on field bunds and keeping cattle nearby (Baum and Migot-Adholla, 1982).

In Nigeria at Bakolori, where a substantial market town was drowned by the reservoir (Wallace, 1981), people were moved on time to new sites, but there was no provision for economic life. There was no water, no fuel and compensation was delayed. By the time people had secured their compensation by direct action, a third of the resettlement villages had been abandoned, as people had cut their losses and moved (Bird, 1984, 1985).

Issues Arising in Planning Settlement Schemes

If it is necessary to provide new villages, several difficult questions have to be faced, such as whether to try to integrate people of several tribes, or to soften the blow of translocation by keeping social groups together. On housing it has to be decided whether to build an "improved" house, whether indeed to give nothing on the grounds that people normally build for themselves, or whether to help them do this by a loan. Underlying these issues is the question of whether security of ownership of the house can be combined with an insecure annual agricultural tenancy. There are very important issues to consider in tenant selection criteria and choice of tenancy size:

- Is there a clear understanding of scheme objectives and the relationship of this to tenant selection criteria? The best discussion of this is in Clayton (1978). The target of a high farmer income will reduce the number of settlers and the impact on the unemployed. Lower incomes may not halt urban drift (ILO, 1972, on this conflict). Maximum production needs experienced farmers, and the landless/unemployed are often young with non-farming backgrounds. Because they are young, they have small families, and therefore, not enough family labor for the tenancy.

- It is not often considered whether, given human variety, it is justifiable to plan on uniform holding size. It is a statistical inevitabiltiy that there will be below average farmers, and these may absorb a disproportionate amount of management time if they cannot be given a smaller holding (Tiffen, 1984).

- One of the objectives may be equity of income distribution, but Clayton has shown there is a spread of income within schemes in Kenya, and farmers accept this as reflecting different family attributes (Clayton, 1978). There is also a very wide range of incomes on the Gezira (Salam, 1979).

Many of the issues raised in this section assume a settlement type scheme. The question as to whether this organizational type is desirable is raised in the following section, where the management implications of tenancy schemes are considered.

Tenure and Management on Settlement Schemes

Settlement schemes are those where land as well as water resources are owned or controlled by the scheme authority, and on which farmers have the status of tenants, obliged to follow orders with respect to most important farming activities.

Justification for Settlement Schemes

The usual justification for this arrangement is that the state, or a commercial company, is providing important and expensive assets, and must be able to ensure that they are used in a manner that will ensure high yields and a good economic return (Tuckett, 1977). Usually in Africa the farmers for whom the schemes are intended have no experience in irrigation, so it is felt essential that they farm under direction, at least in the initial years. In practice, the teaching period gets extended for decades. A settlement scheme enables rules on cropping patterns, irrigation practices, rotations and cultural methods and timing of operations, etc., to be enforced. Frequently, marketing has to be through specified outlets, so that the authority can recover loans and water and maintenance charges, etc. Part of the rationale for the authoritarianism of management, as in Mwea, is that in irrigation timeliness and effective crisis management is all important (Chambers and Moris, 1973).

The undoubted complexity of water delivery, maintenance and repair and cost recovery, etc. means that it is normally much simpler to entrust these functions to a new state agency than to assist farmers to set up their own institutions and to provide them with tuition. This is especially so in cases where the advantages of irrigation are not clear to the farmers, when there is need for some coercion to make them take up irrigable land and to farm it intensively. This was frequently the case in some systems introduced in areas of low population density where rainfed agriculture remained a viable alternative.

The settlement schemes give planners further advantages. Plot layout can be decided by technical requirements, rather than by existing ownership patterns. The size can be controlled according to the scheme objectives. Suitable tenants can be selected instead of relying on those already there (Palmer-Jones, 1981, summarizes the advantages quoted by advocates of settlement). The system should theoretically also facilitate bulk-buying, low marketing costs and low administrative costs (El Hadari, 1972).

The structure of the settlement scheme is supposed to prevent fragmentation of holdings by inheritance, and to protect the tenant from unwisely mortgaging his land and losing it by indebtedness (Gaitskell, 1959).

Rights and Duties of Tenants and Management

Degree of Formalization. In the Gezira the tenant had a written agreement, which he signed annually until 1950. By then tradition implied continued renewal, if the tenant had kept to the terms (El Hadari, 1983). An initial written agreement has been the general model in the Sudan, though, as we have seen, it was not always signed if tenants disputed the terms (Pearson, 1980). Tenants have individual accounts they are entitled to inspect.

It is rarely clear in the literature on other anglophone countries how the terms of his lease were conveyed to the tenant, and whether or not he had an individual written agreement, and what occurred if changes were made in the conditions of the tenancy. Tenants on the CDC scheme at Vuvulane in Swaziland certainly had a lease, which provided for increases to be made in rents at the end of ten years (Tuckett, 1977). In Kenya all settlement schemes run by the National Irrigation Board come under the Trust Land (Irrigation Areas) Rules of 1962 and the Irrigation Act of 1966, which give the scheme management powers to control virtually all economic activity. Separate accounts are maintained for each tenant (Fitter, 1983).

In some francophone countries the legal contracts are with cooperatives (see below). However, in the case of an irrigated palm plantation in Benin peasants were said not to be clear whether it was functioning as a cooperative or as a state farm which should pay them wages (Dissou, 1985). In Burkina Faso all land equipped with irrigation automatically becomes state land. The allocation to peasants fail to make clear the legal position on improvements.

Duties of Tenants. The Vuvulane scheme seems fairly typical in the powers given to the irrigating authority. The management could "define standards and . . . issue instructions to cover:

- Strict control over livestock and grazing areas;

- Construction, maintenance or demolition of buildings, roads, canals, drains and other structures;

- Use of vehicles;

- Prevention and control of pests, diseases, fire and soil erosion;

- Maintenance of boundary beacons;

- Sanitary arrangements and hygiene; and

- Agricultural methods and practices in general" (Tuckett, 1977).

As in the archetypal Gezira, management invariably decides crops, cropping patterns and cultural practices for at least the main crop. Almost all schemes require the main crop to be marketed through the authority; in the case of one crop schemes like Mwea, this meant control of all marketing.

In francophone Africa the tenant is commonly obliged to become a member of a cooperative. The authority deals with the heads of the cooperatives. This pattern was initiated by the Office du Niger (de Wilde, 1967). On the large Senegalese schemes the cooperatives were at first the means by which the authority, SAED, could distribute inputs and market outputs. However, they have evolved to permit closer control. Peasants are formed into "groupements de producteurs" of 12 to 20 farmers and equipped with animal power. One SAED employee supervises two groups. A legal contract links the peasant to the group and the group to SAED. The duties of peasants are to prepare seedbeds, sow in line, weed, maintain and to repay collectively the debts of all members. SAED must provide water control, execute the necessary cultural operations and assure the supply of factors of production and advice (Diagne, 1979). In Niger the cooperatives are formally responsible for planning all agricultural operations and for irrigation operation and maintenance. The land and the permanent infrastructure belong to the State, but are put at the disposition of the cooperative. In practice, the Director of the Scheme, an employee of the National Authority for Irrigation (ONAHA) is the key person. In November 1982 a national seminar recommended that more functions be delegated to the cooperative officers, but that the staff should continue to be responsible for the cropping plan, calculation of dues and management of funds (Cissé, 1985).

The functions of the management authority everywhere include the delivery of water. Schemes vary as to whether management is also responsible for mechanized operations. This is most frequently the case with rice and sugar schemes, e.g., Mwea, Vuvulane. The evolution in the Sudan has been for management to perform more and more of the agricultural functions.

<u>Sanctions for Non-Performance</u>. Formally, the main sanction for non-performance of work by the tenant is eviction. The need for this sanction is one of the main justifications of the tenancy system. It is, however, difficult to enforce since the political system gives tenants some leverage and it is difficult to replace tenants. When management tried to evict some 500 tenants from New Halfa after years of poor

performance, protests secured the return of most to the holders or a relative (Pearson, 1980). In the Gezira management could enter the tenancy to perform the neglected function, charging costs to the tenant's account (Salam, 1979). In Mwea there is a series of warning letters and fines before eviction (Clayton, 1978). In Senegal tenants have been dismissed although the failure of the rice crop was at least partially due to a strike by tractor drivers (Bonnefond and Caneil, 1981). Generally, management has a legal right to punish tenants for non-performance while tenants can at best exert informal pressures on management to reduce charges when services are not delivered.

Methods of Charging Tenants for Management Services. The Gezira system of rewarding management by a share of the main crop was followed on schemes initiated in the 1960s, but changed to fixed charges for land and water in the 1970's (Ebrahim, 1983). The sharing system had the advantages of providing an incentive for management efficiency, and meant that management shared with tenants the risks of low prices, losses from disease, etc. This was particularly important in the 1930s (Thornton, 1972). The fixed price system means that the tenant carries the whole burden of risk (Benedict, 1982). The drawback of the cotton sharing system became apparent when other cash crops entered the rotation in the 1960s. As tenants paid only on their cotton, they gave preference to other crops. The pros and cons of extending the sharing system to other crops and of rental systems are discussed in Salam (1979) and El Hadari (1972).

Tenants on NIB schemes in Kenya pay a combined land and water charge which varies from scheme to scheme, but which is theoretically calculated to cover current expenditure and to make a contribution to investment costs. In fact, it has to be fixed in relation to the tenant's need of a minimum income, and only at Mwea is it high enough to cover these costs (Fitter, 1983).

Tenants may also have to pay for other services such as tractor plowing, crop spraying, fertilizer application, etc. In some cases these are compulsory, and are automatically deducted from the tenant's account (e.g., Mwea, Gezira, Rahad and large schemes in Senegal). In a few cases, tenants have the option of asking management for them, or making their own arrangements (e.g., for some services at Vuvulane [Tuckett, 1977]). In the Gezira management supplied tractor services for cotton, but tenants could and did hire tractors from other sources for their other crops. Gezira tenants were charged a standard rate for these services, i.e., it made no difference if they had one or two crop sprays, light or heavy plowing (Salam, 1979). The complications of the charging system, and the standardization, made it very difficult for tenants to see any relationships between inputs and income, as noted both in the Gezira and Mwea by several observers.

Attitudes of Tenants to Their Status

Tenant is a misleading word to describe the status of a man on an irrigated settlement scheme. His obligations are not limited to payment of rent and certain conditions on maintaining the farm in good order, but include the acceptance of detailed orders. It has been said that farmers on large Senegalese schemes "could best be called laborers, if only their position offered them the security of a wage" (Diemer and Van Der Laan, 1983). The decision-making sphere of Gezira and Rahad tenants on controlled crops is limited to whether to work themselves, or to hire others to work for them (Gaitskell, 1959; Barnett, 1977; Salam, 1979; Benedict, 1982).

The word tenant carries connotations of inferiority that is often not acceptable. The reason tenants refused to sign the annual agreement on the Gezira in 1950 was that they wanted the word tenant changed to partner (Gaitskell, 1959). However, the acceptability of the status is best measured by the level of demand for scheme land, rates of turnover, etc. It can also be analyzed by looking at points of dispute between management and tenants.

Demand for Scheme Land. This is clearly related to income levels. Gaitskell (1959) notes that tenancies had to be given to immigrants during the depression; this aroused resentment among the locals in the early 1950s when incomes were high and tenancies in demand. In the 1970s, when incomes were again low, El Hadari found that only about 20 percent of existing tenants desired a tenancy for their sons, but they themselves valued it because, being old and uneducated, they did not have other income-earning options. The question of other opportunities is important; demand for tenancies is high in Kenya because of land shortage (Fitter, 1983). Clayton (1978) found there were more "discipline" problems on Mwea when incomes were low. The Perkerra scheme has had low incomes and high turnover (Chambers, 1973). There are indications that settlers on the Office du Niger abandon old areas as yields fall and move to newly developed virgin soils (de Wilde, 1967). In Kou, Burkina Faso the number of local participants was low and fluctuating compared with the immigrant settlers because the locals had access to rainfed farms and livestock (Ouedrago, 1979).

Campaigns for Changes in Terms. Main opposition to management focuses on five issues.

1. Rights at termination of the tenancy by death or dismissal. Tenants at Mwea demanded the right to nominate a successor, and this was conceded by management to lessen tenant antipathy to the annual nature of his license (Giglioli, 1965). Tenants in Swaziland delayed signing their leases until they got satisfaction on inheritance rights for one of their children and compensation for improvements in the event of eviction (Tuckett, 1977).

2. Money issues and control of marketing. It has been observed in Kenya that tenants' suspicions focus on money mangement, prices and tenant accounts. This was noted quite early in Mwea (Chambers and Moris, 1973) and has led to production boycotts and "black market" sales on other schemes (Fitter, 1983). The 1946 tenants' strike in the Gezira was triggered by their

discovery that some of the proceeds of wartime sales had been paid into a Reserve Fund (Gaitskell, 1959). Vuvulane farmers insisted on payment for actual sucrose delivered, although CDC thought it fairer to pay on average sucrose content. They persistently refused collective marketing arrangements for their other crops (Tuckett, 1977). In Burkina Faso peasants left an official scheme producing green beans for export partly because of management failures in delivery of services, but also because they felt able to get better prices for themselves. They bought pumps and established private farms (D'At de St. Foulc, 1985).

3. Alternative crops, additional crops. Linked to the marketing issue, tenant farmers are often at odds with management over which crop to devote most attention to, the growing of additional crops, keeping livestock, etc. Numerous studies show that they respond to local market forces and consider family consumption needs, while management aims to produce a certain crop according to national economic plans. Disputes occur over issues such as growing of vegetables on field bunds and retention of cattle contrary to scheme rules (e.g., in Kenya, Baum and Migot-Adholla, 1982). In the Sudan most observers have noted the conflict between tenants and management on the importance of sorghum, and the variable interest in official crops such as groundnuts and cotton, according to price factors (e.g., Benedict, 1982; Faki, 1982; all reports on Khasm el Girba/New Halfa).

4. Housing restrictions. In schemes where housing is provided by management, there is often resentment and evasion of rules and restrictions (Baum and Migot-Adholla, 1982; Chambers and Moris, 1973; Heinritz, 1972).

5. Social facilities. On the more successful schemes, where tenants' aspirations rise beyond basic business of survival, they begin to demand schools, health clinics, etc., which management may not feel it is their business to provide. At the same time, the scheme structure and the lack of a normal local government with its own revenue (which might conflict with management's total control) makes it difficult for tenants to use normal mechanisms for obtaining these. The difficult relationship between the Gezira management and Village Councils from the 1940s is discussed in Salam (1979). The problem was well recognized earlier (Beer, 1953), but never satisfactorily solved. The same conflict arose in Mwea (Chambers and Moris, 1973). At Vuvulane CDC first provided schools and clinics itself, but later negotiated for the Ministries concerned to take them over (Tuckett, 1977).

Changes in Tenure Over Time

Whatever the legal position, tenancies become heritable and certain other changes occur. In the Gezira there has been an increasing number of half-tenancies (subdivision being permitted to this extent, but no further, and an increase in the numbers held by widows and minors. In 1974, 11,000 of the 95,000 tenancies were held by women, and another 600 by minors (Salam, 1979). Tenants consider themselves normal landowners, and frequently install a "wakil" (deputy) who manages the tenancy in their absence. For crops which they market themselves they may install a laborer paid on the sharecropping basis normal in the Middle East (Faki, 1982; Heinritz, 1972; Hoyle, 1977; Barnett, 1977, have references to major schemes; Adam, 1971, goes into more detail on types of sharecropping arrangements on private pump schemes). The "wakil" may well pay over the tenancy revenues to several heirs, in accordance with the "sharia" rules, but this does not seem to have been investigated. Over time the tenants become older, less able to work themselves, but officially they are not allowed to reduce their holding size. On Kenyan schemes it has been reported they are unwilling to pay the going wage-rate to their sons, and so lose their services (Clayton, 1978). This must reduce the efficiency of farm operations. In the Gezira fathers pay the going rate to sons they want to retain (Barnett, 1977).

It is suspected that informal leasing and sharecropping arrangements generally make an appearance on older schemes, but this is seldom investigated. Certainly on the Nyanyadzi scheme in Zimbabwe, established in 1935, it was noted in 1981 that some registered plot holders had rented out parts of their holding to others (informal report). Such a development would, of course, only occur where the scheme was offering the opportunity of earning a reasonable income.

Management Implications of the Tenancy System

For Management. In certain situations settlement management can be relatively efficient. It makes it possible to have a simplified canal layout. The system can be operated with low-qualified staff, provided a good monitoring system is maintained, as at Mwea and Vuvulane (Clayton, 1981; Cobban, 1981) and in the Gezira (Gaitskell, 1959). However, when the management system involves the delivery of many mechanized services, in situations where spare parts and fuel are difficult to obtain, the young graduates available to staff it may be faced by a task beyond their capacity (Benedict, 1982).

The disadvantage of a centralized system is that any mistakes made are on a large scale (Salam, 1979). Bureaucratic systems may also not be able to respond flexibly to crises, e.g., by paying higher wages, authorizing overtime, etc. This is particularly serious when two crops have to be fitted into the farming year and timeliness is crucial. It is perhaps significant that both the Gezira and Mwea are one season systems. Many of the unsuccessful Kenyan systems try to obtain two crops, as do the unsuccessful large schemes in Senegal. Bureaucratic management also seems to succeed with sugar.

For the Tenant. It has been frequently noted that tenants assume that because government owns the land and the irrigation system, government has the duty to maintain it (e.g., D'At de St. Foulc, 1985). This is particularly so on schemes that do not offer good incomes.

The same attitude conditions investment policies. The peasant is unable to invest savings in purchasing more land which, as D'At de St. Foulc (1985) remarks, removes a dynamic found in capitalist systems. He may instead invest in livestock, but this has problems if grazing areas are restricted (Beer, 1955). Fitter (1983) notes regarding Kenyan schemes:

> "Tenants cannot use their holdings for securing loans, they cannot subdivide their holdings to provide a living for their sons, they cannot choose their place of residence or even modify their quarters without permission, and there is always the threat that the tenancy may be taken away. Under these circumstances, settlers view their tenancy as a means for generating income for investment in a variety of different enterprises, both on and off the scheme, to secure an alternative livelihood. The consequences are obvious: diversion of profits and attention towards off-scheme activities." The same attitudes have been noted in the Sudan (Salam, 1979).

The system also blocks the tenant's ability to experiment with new varieties, crops or techniques, or to respond to new market opportunities. Nevertheless, some experiments are made and spread; for example, the new watering techniques in the Gezira (Barnett, 1977).

When marketing is controlled, costs of services standardized and payments made by installments, it becomes quite impossible for tenants to relate inputs to outputs and to calculate financial benefits of different policies (Salem, 1979; Chambers and Moris, 1973).

Issues for Consideration

Advantages and Disadvantages of Settlement Schemes. It is time to consider seriously whether the settlement model is essential for the introduction of irrigation in new areas. It has serious disadvantages in the complexity of functions imposed on often inexperienced management staff, and even more serious social disadvantages in cramping innovation and personal development.

Tenant status has been thought essential to instruct inexperienced farmers. There is evidence that Africans can learn new techniques very quickly when it is profitable. This was observed on the early pilot projects preceding the main Gezira scheme. It was reported in 1911:

> "It is wonderful to see how these novices at cotton growing have, through the influence of their neighbors, cultivated their own fields as well as if they had been used to cotton growing all their lives" (Gaitskell, 1959).

In Burkina Faso farmers successfully started their own green bean gardens after two years on a scheme (D'at de St. Foulc, 1985). Farmers on the mainly unsupervised village schemes in Senegal get better yields than those on closely supervised large schemes (Diemer and van der Laan, 1983). However, on the relatively successful Vuvulane scheme, CDC officials felt cultivation standards would fall if "discipline" was not enforced. As social pressures made it difficult for African staff to recommend eviction, it was felt expatriate management was still necessary after 20 years (private information). Tenants did without guidance on the 30 percent of the plot under their own control, growing and marketing vegetables, potatoes, etc., which are not inherently simpler crops to manage than sugarcane. Could the lack of enthusiasm for intensive work on sugar be related to the sugar price?

From the 1950's there has been discussion in the Sudan about the attitude of dependence on management created by the Gezira structure, and on whether or not the tenant had the capacity to evolve into a successful entrepreneur if management relaxed control. The main activity of the Tenants Union has been to campaign for management to undertake more functions and to bear more costs, which has not been regarded as a promise of positive farming attitudes. However, the evidence of Wad-el-Naim's village farming experiment suggests that tenants can and do innovate and respond to market stimuli when allowed to do so. It is the layout of the fields and canals and the methods of water control which make it extremely difficult to allow individual control of cropping operations on the main scheme (Swan, 1985). This illustrates the importance of thinking out the direction in which it is hoped the scheme will evolve at design stage. The debate about methods to reduce dependent attitudes, and whether it was desirable and possible, given the layout, to help the tenant evolve into a decision-making farmer, is found in Beer, 1955; Gaitskell, 1959; El Hadari, 1972; Thornton, 1972; Barnett, 1977; and Salam, 1979.

If it is decided to give the farmer more freedom and responsibility, the stages and methods by which this can be done need consideration. It may be possible to transfer functions to a cooperative, and it may be necessary to have a sham cooperative stage when in fact most decisions are still being taken by staff (Cissé, 1985). The withdrawal of staff will not be easy. It needs to be considered how a settlement scheme can cater for human variety, and for changing needs during the life-cycle, with the same flexibility as in unregulated tenurial systems.

What is the relationship of size of scheme to managerial structure? If it is possible to have large schemes in Asia without controlling tenure, is it not possible in Africa and more constant with human aspirations and dignity?

The Provision of Housing, Social Services and the Relationship to Normal Ministries and Local Governments. While housing, or money for rebuilding, and the replacement of existing social services, are obviously required as part of the compensation for those displaced, it needs to be considered how far it is the duty of management to provide or manage these things once the settlement is established. This involves consideration of management and tenants' relationships, including their taxation position, with regard to normal central and local government services. There appears to be some move back, in some African countries, to restoring the effectiveness of local government. For example, whereas SAED in Senegal was once an all-embracing rural development agency, it has now to work alongside elected Rural Councils (Mathieu, 1983). There could well be conflicts of jurisdiction and of ethos between autocratic settlement management and elective local authorities. These issues require being thought through, country by country, if management is to have clear terms of reference.

Tenure and Management on Extension-Style Schemes

On extension-style schemes farmers retain their original holdings, and changes in tenure are either not made or are agreed. Irrigation methods are introduced by demonstration, teaching and voluntary persuasion. Following are a few examples.

In a scheme sponsored by Shell in southeastern Nigeria a socio-economic study was first made. It was realized farmers feared that government would take over their land. The agronomist appointed to encourage self-help tactfully did not go on farmers' land until invited. Four families agreed to share work to convert their swamp into a fish pond, dam and two acres of irrigated rice, and made their own agreement on the division of the irrigated area (Oluwasanmi et al., 1966). By 1974, despite an intervening civil war, there were 600 acres of irrigated rice (Anthonio and Ijere, 1973). Similar community development methods were successful in introducing rice cultivation in northern Ghana in the 1950's. Again, villagers came to their own agreement about management and tenure (Crosser, 1982).

In northern Nigeria the Dutch consultants originally recommended purchase of land and a settlement scheme in Kano. This did not happen; those farmers included in the scheme retained most of their holding. The management found it difficult to adjust: "Some farmers cooperate, but it is not satisfactory because we have to ask farmers, not tell them what to do." There was certainly an initial period when many farmers preferred to continue growing guineacorn in the rainy season, which effectively prevented wheat cultivation in the dry season (Wallace, 1981). However, by 1984 personal observation from the road suggested farmers were growing a second crop of wheat, tomatoes or onions. Roy (1983) reported that many farmers thought that irrigated agriculture was profitable, provided they could get inputs on time. There were sometimes violent confrontations with officials if there were delays in the supply of promised seed, tractor services, or other inputs.

In Senegal the village schemes have been essentially on the extension model, formed after requests from the peasants when they had seen a successful demonstration. Land tenure was changed, but by agreement (Diemer and Van der Laan, 1983). Occasionally, there has been no intention to change tenure, but this has happened because of inadequate preliminary investigaions into social structure. The Gambia case has already been cited (Dey, 1980). This can delay adoption of new practices.

On the whole, the record of extension, when tried, seems successful, provided the technique offered was genuinely profitable. There is, however, often a slow start, with only a few individuals or groups accepting the experiment initially. After three or four years adoption accelerates.

Areas Where Further Research is Needed

There is not much in this chapter on francophone countries other than Senegal. This probably reflects lack of time for a full French literature search, since francophone scholars seem to give more attention to land use and legal issues than anglophone ones. It is also suspected that much more Sudanese literature is available in the Sudan. It is noticeable that the best-covered countries in this chapter have been Sudan, Senegal and Kenya. Additional research is almost certainly required elsewhere. In Nigeria the initial disastrous years of large northern schemes have been well cataloged; the state of the schemes five or ten years later is not generally known. Other areas of research include:

- The issues connected with water rights, water use licensing, water use monitoring and existing water use in partial control systems certainly need further investigation and consideration.

- There is virtually no information on the tenure and management of large state farms, commercial estates, large private farms or small private farms, which are introducing new irrigation technology.

- The connection between tenancy and a dependency complex needs further investigation. The methods by which management can withdraw after an initial learning phase have not been considered. The investment patterns of farmers on settlement schemes seem only to have been researched in the Sudan.

- Similarly, the issues of the relationship of a settlement scheme to the authorities responsible for normal local government services seem only to have been considered in the Sudan, and even there, the most challenging articles are by Beer in the 1950's.

- There is a whole range of issues on the relationship between equity of income distribution, size of holding and the retention of original land rights so as to encourage flexibility, personal responsibility and individual investment, which have not been thought through.

CHAPTER EIGHT

IRRIGATION PROJECT ECONOMICS

by

Thomas M. Zalla[1]

Irrigation as a Privileged Solution

There is considerable evidence supporting the conclusion that the introduction of irrigation into African production systems in recent years occurred because it is what might be termed a privileged solution. The economist A. O. Hirschman has coined the concept of a "privileged problem." By this, he means a major problem area which, while often of long-standing origin, comes to policy-makers' attention in a given period as requiring remedial attention. In this sense, drought within Africa became in the mid-1970s a "privileged problem:" a situation which in the larger context of food surpluses being generated on other continents appeared no longer tolerable. Why should hundreds of thousands of people and animals die when technologies capable of supporting them were already known?

The Sahelian drought of 1972-73 thus brought the persistent problem of African droughts to international attention, just as did the 1983-84 Ethiopian drought a decade later. A common agreement among donor nations that the situation must be addressed stimulated a search for promising technological interventions. In particular, World Bank and other multilateral funding became available, as did (though to a much lesser extent) USAID funds. Two main technological solutions were available which seemed from international experience to alleviate or even prevent the worst impacts of drought: range management for the livestock subsector, and irrigation for crop development in semiarid environments. In both instances there were earlier experiments under the colonial regimes which ought to have provided grounds for moving cautiously. However, the status of these two technologies as "privileged solutions" meant that local experience was ignored. Africa, it was assumed, could benefit from technology transfer, bringing into play at the local level new technologies which have already proven their worth on other continents.

The attractiveness of irrigation as a preferred choice for stabilizing food production was especially high after the 72-73 drought. In addition, by the mid-1970s it was clear that major irrigation investments in Asia were beginning to pay off, even generating food surpluses in situations which had been regarded as hopeless only a few years earlier. It seemed reasonable to assume that the same technologies might yield similar results in Africa, particularly within parts of the West African Sahel where large-scale irrigation along Asian lines was

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technically feasible.

With regard to the proposed dams along the Senegal River, Reboul (1982) argues that three assumptions were made by donors in deciding to fund these major investments: (1) drought is bad per se; (2) irrigation is technically feasible and profitable; and (3) there is no real alternative for crop development in these environments. Of course, if such premises are accepted as facts, then economic analysis of irrigation in comparison to alternatives becomes unnecessary. Indeed, the striking feature about the large irrigation investments which were undertaken in the 1970s is the lack of prior economic analysis based on realistic production data. To be sure, economic appraisal was usually required by donors as a preliminary step in project development. But the decision to implement irrigation projects preceded economic and financial appraisal, and governed the selection of assumptions to obtain the necessary rates of return. The "privileged" status of irrigation projects meant that associated premises about the environment were not subject to scrutiny; when adverse data on costs and yields surfaced, assumptions were changed so that projects still appeared profitable.

The most recent evidence in support of this observation comes from the Wageningen study by Van Steekelenburg and Zijlstra for the EEC (1985). As earlier noted, the Wageningen team visited eleven EDF-financed projects in six African countries. They found that most projects aimed at a 200 percent cropping intensity, which was rarely achieved. In all cases projects had been justified showing an economic internal rate of return (EIRR) of 10 percent or higher. To arrive at these figures, "excessively optimistic estimates of development possibilities, of production figures and of implementation costs" had been employed (p. 66). When recalculated on a more realistic basis, the EIRR became negative on four of the eleven projects. Only one (where the project funded only diversion weirs for pre-existing community schemes) reached a 10 percent EIRR level. While project files were in good order, "it was difficult to trace the very beginning of project proposals because the preparatory/prefeasibility studies were often not in the files" (van Steeklenburg and Zijlstra, 1985:7). In commenting upon various types of appraisal which might have been applied, the Wageningen team notes:

> In none of the projects that we evaluated was anything like such an assessment made before funds were committed. The general story is that of a nice looking valley or plain with a river running through it, which according to engineering standards could and should be converted into the "granary" of the country. And so work began! (van Steeklenburg and Zijlstra, 1985:28-29)

The notion that on a single site a country can create a "granary" to prevent famine and reduce food imports remains a potent dream (here one is reminded of Egypt's ambitious plans for reclaiming its western desert). Never mind that the foreign exchange costs of producing wheat in remote African locations exceed by several times what it would cost if imported; that the inputs required in irrigated agriculture are often heavily subsidized; or that most irrigation projects run at a financial loss, and their supervisory agencies are paid for from public funds. To African policy-makers, facing annual food deficits and living in land-locked countries crossed by a major river, irrigation retains its allures as the more "modern" technology capable of meeting their national needs. In many African countries, irrigation projects remain privileged even under conditions of marked economic stringency.

To be sure, much of investment in irrigation in the drought-stricken areas of the sub-continent was politically rather than economically motivated. Donors had to appear to be doing something constructive to respond to widespread famine and starvation of the early 1970s. Unable to have much impact on institutional, trade, marketing, pricing and other policy constraints, investments in irrigation offered a tangible, highly visible and politically attractive alternative that could absorb large amounts of money. It was this desire to be seen to be doing something rather than a belief in the inherent viability of irrigation that led to the decisions to proceed with irrigation projects before doing any serious economic analysis.

Today the pressure to appear to be doing something has shifted from bricks and mortar to the policy arena. Tangible investments are receiving greater scrutiny as budget constraints are forcing donors to be more selective. Past input-output assumptions have proved demonstrably unrealistic, largely because of policy related variables. In addition, huge shipments of food aid, combined with ample harvests, have led to price depressing grain surpluses in many areas. The high unit costs and poor economic performance of most government sponsored irrigation projects becomes more glaring in such a situation.

It seems likely that insofar as external assistance is concerned, irrigation projects can no longer expect automatic preference. They must be justified with realistic estimates based on actual performance, in the same way that other options for rural development are being assessed.

If so, the economic aspects of African irrigation become central to the decision of whether to proceed with further irrigation projects. The overriding policy question becomes whether returns to rainfed agricultural projects or to alternative approaches to irrigation might be higher. This raises, in turn, problems arising from a chronic cost-price squeeze created by a cap on output prices (caused variously by price controls, competition from synthetics or world oversupply of certain crops).

When irrigation is placed in remote sites, for example, countries often must finance large infrastructure costs and incur high transport costs for inputs and outputs which somebody must absorb. Once schemes are in operation, they are likely to encounter a severe recurrent cost constraint. Most countries subsidize certain operations in an attempt to make commercial irrigation more attractive. Is this a wise policy? Farmers who are still at a subsistence level will have obvious difficulties repaying irrigation charges, making cost recovery a major problem almost everywhere on the continent. This, in turn, ought to influence the decision of whether or not to seek external loan financing.

Where external financing is required, project appraisals frequently assume a 200 percent cropping intensity, higher mean yields and more efficient input-output relationships than the larger economic, institutional and managerial systems can sustain. Finally, as a country's balance-of-payments deteriorates, it may find the higher import content of modern irrigated production unsupportable. In such a context issues related to irrigation economics overshadow other aspects of African irrigation.[1]

Economic Benefits and Costs Related to Irrigation

Cost recovery problems relating to irrigation projects stem, at least in part, from the nature of some of the economic benefits that such projects provide. It is instructive for our analysis to begin with a review of the major benefits and costs associated with irrigation projects. Some of them are indirect or secondary. That does not make them less real, only more difficult to identify, measure and recover.

As a first step, planners need to distinguish between private or financial profitability and national, social or economic profitability. For any investment cost and crop combination, there are a set of policies that can make the investment profitable from the private point of view. Input subsidies, not charging for system amortization, cheap credit, and customs duties on competing imports are just a few of the factors that cause private and national profitability to diverge. In looking at irrigation system economics, one needs to abstract from such particularities as much as possible. This implies basing the economic analysis on international prices and adjusting for transportation and different labor costs without referring to producer prices in a particular country. At the same time, this does not imply ignoring financial returns. Producer prices will certainly influence the magnitude of farmer response and attainment of project output objectives on which the economic analysis is based.

Irrigation projects generate benefits in the form of increased output resulting from:

- changes in land under cultivation;

- changes in the productivity of land and labor;

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[1]Apart from general sources on irrigation economics, such as Carruthers and Clark (1981) and Bergmann and Boussard (1976), we especially recommend the FAO (1986) study, Irrigation in Africa South of the Sahara; Pearson et al. (1981), Rice in West Africa; Hazelwood and Livingstone (1982), Irrigation Economics in Poor Countries; and various papers contained in Morris (1980), Second Workshop on Sahelian Agriculture. Work in this chapter draws heavily upon the FAO paper and upon preliminary comments received from Edward Sparling of Colorado State University.

- changes in employment; and

- increased security of crop production.

To arrive at net changes in output we need to allow for production forgone by:

- land now under irrigation;

- land away from which farmers are shifting; and

- labor now working in the irrigation project.

Occasionally, irrigation projects in Africa will offer other benefits such as increased availability of water for household and livestock use, improved flood control and expanded opportunities for fishing.

Increased costs associated with irrigation projects arise from:

- the cost of establishing and operating the irrigation project;

- crop production costs; and

- subsidies and other forms of protection or price support related to the increased output.

In addition, the projects often create or aggravate health problems, the cost of which are seldom borne by the project itself.

These categories of costs and benefits overlap to some extent. It is important, therefore, to pay attention so as to avoid double counting.

Types of Benefits in Irrigation Projects

Increased Land Under Cultivation. The most obvious increase in land under cultivation occurs on the irrigation perimeter itself. Some or all of this land may not have been previously cultivated. Alternatively, it may only have been extensively cultivated during the rainy season or cultivated only during periods of flood recession. To the extent that the cropping intensity increases, i.e., from less than one to 1.4-1.9 crops per year, the project generates an effective increase in land under cultivation. Moreover, any increase in land under cultivation outside of the perimeter, but arising from the presence of the perimeter, such as cultivating the borders of drains or exploiting a higher water table for irrigation of adjacent areas, also constitutes an increase in land under cultivation arising from the project. At the Galmi perimeter in Niger, for example, such increases equaled 15-20 percent of the area of the perimeter.

On the negative side, farmers exploiting the irrigated land made available by the project may stop cultivating land elsewhere. This would include rainy season land as well as any dry season irrigated production, but only to the extent the land is not picked up by other farmers. In a situation of land scarcity one can sometimes assume with good justification that other farmers are sufficiently underemployed, especially during the dry season, that any land left uncultivated by project participants will be picked up by others. As a result, there may be no net increase in area cultivated. This is not usually the case of land cultivated during the rainy season though. In most instances in Africa, there is little underemployment at that time.

Where water rather than land is the scarce factor, the tradeoff between alternate uses may not be proportionate. Hazelwood and Livingstone (1982), for example, show that large farm irrigation can be complementary to peasant production where the two competing systems utilize water at different times of the year. By accepting a 0.5 percent decrease in peasant area cultivated during the flood season, large farm production in the Usangu plains of Tanzania could expand by 12 percent of the area under peasant irrigation. This arises because the large farms plant before the rains and utilize only a small amount of water during the flood season when peasant irrigation is in full swing.

In commenting on the clash between economic and technical efficiency the authors note that:

> The large farm was technically more efficient...in the use of water...but it demanded water at a time when it was particularly scarce, whereas small farms demanded most water when it was least scarce. Despite their inferior technical efficiency, the economic efficiency of the small farmers in the use of water was therefore higher than that of large farms.
>
> ...It is uneconomic to devote resources to economizing in the use of something which is not scarce. (Hazlewood and Livingstone, 1985:128.)

<u>Increased Productivity of Land and Labor</u>. In addition to increasing cropping intensity and area under cultivation, most irrigation projects increase the productivity of both land and labor. Indeed, the huge capital investments required by irrigation projects can only be justified where significant increases in productivity result. By providing better control over water, making special efforts to ensure that other inputs are available when needed and by providing research and extension support, physical output per unit of land, and hopefully, labor rise sharply in successful irrigation projects. Better control over water also expands the range of possible cropping patterns and the quality of output, contributing to a greater value of output per unit of land and labor.

Problems arise with irrigation projects in Africa that increase output per hectare but not per unit of labor. Unless farmers are captive participants, the ready availability of rainfed land frequently causes farmers to divide their labor between irrigated and rainfed lands. As a result, technical input-output relationships realized in the perimeters seldom attain the levels assumed by irrigation specialists. These less favorable input-output relationships aggravate cost recovery problems on the perimeters, even though total returns to the farmer's own land and labor resources usually increase. The only consistent solution to problems relating to cost recovery and returns to investments in irrigation is to ensure that returns to labor on the perimeter are significantly greater than non-project returns. To determine whether this will be possible requires an in-depth study of farming systems prior to the introduction of irrigation.

Changes in Employment. Whereas rainy season irrigation faces competition for labor from rainfed agriculture, dry season irrigation faces competition for labor from urban casual employment and migration. The opportunity cost of this labor, i.e., the output forgone by the economy, when used for irrigation depends on whether these alternative opportunities are available in-country or in neighboring countries. Measuring the net-forgone output of labor which would otherwise have migrated to a neighboring country is particularly difficult.

Where labor employed in irrigation would have migrated to a location in-country in the absence of the irrigation project, the social opportunity cost (output forgone) of that labor is usually assumed to be zero. This does not mean the laborer will work for nothing. It means the economy loses nothing by shifting his labor from urban to irrigated farming employment. Any employment he would have had, and any output he would have produced in the area to which he would have migrated will, in most cases, be provided by remaining laborers who are underemployed. They simply have less leisure, something they do not want anyway. In the context of chronic underemployment that typifies most of Africa, we usually assume that leisure has zero social or economic value.

Where labor attracted by an irrigation project forgoes international migration and employment, the net-output forgone is equal to the amount of the workers' remittances. Some planners would add the value of his consumption as well since because of his absence the economy does not have to provide that. However, that consumption is both a cost and a benefit when provided in-country and so cancels out on a net basis.

Valuing labor drawn away from international migration is a special problem for irrigation projects since many such projects are located on rivers that serve as international boundaries and where dry-season labor migration is a long-standing tradition. In the absence of information on remittances by such workers--the normal situation--project appraisers normally assume a proportion of total employment generated by the project represents international migration forgone. They also assume a proportion of total earnings that would have been remitted, either in cash or kind. A maximum estimate of total earnings would be what labor that finds dry-season employment in-country earns since those earnings were sufficient to discourage that labor from migrating.

Regardless of the type of migration that is reduced by an irrigation project it is difficult, if not impossible, to recapture this benefit through cost recovery, even though it may be one of the largest benefits arising from the project. It means nothing to a farmer that national output is higher by his not migrating. His personal income will have declined and he will not stay on the perimeter unless he earns nearly as much income or more. Crop prices and cost recovery measures will have to be set so as to insure that this happens or there will be no production at all. In a properly designed and executed irrigation project this can be accomplished by not charging farmers for the full amount of the system amortization and interest. Indeed, the presence of such social benefits that are difficult to privatize is one of the major justifications of concessionary or grant financing by donors. Unfortunately, the logic has often been carried too far and has been used to make uneconomic projects viable from the farmers' point of view. In most cases it would have been better were such projects never undertaken.

Increased Security of Crop Production. A principal attraction of irrigation projects for African policy makers is the increased security of food production which they can provide. The perceived need for increasing food self-sufficiency is the most frequent rallying cry as well as the justification for not taking too hard a look at system economics.

Planners need to be careful to ensure that irrigated agriculture will, indeed, provide increased security of crop production. In many areas, such as the Niger River valley in Niger and the Komadougou River valley in Nigeria, existing irrigation capacity exceeds available water supplies during dry years--the very years during which food security becomes an important issue. Catchment dam systems pose a similar problem. While these systems are still able to assure a viable rainy season crop, their inability to provide a dry season crop when crop prices are at their extreme cuts into system economics significantly. By and large, however, irrigation projects in Sub-Saharan Africa do succeed in increasing the security of crop production.

Placing a value on increased security of production is another matter altogether. Frequently the increased security is being sought with respect to an imported crop in which the country does not have a comparative advantage--wheat in Nigeria, rice in much of the Sahel--and which is important primarily in the diets of the urban population. The very strategy itself can be called into question on equity grounds. So what value to place in increased security? Obviously, there is no set answer. Whatever the response, it will have an impact on the ERR of the project.

Types of Costs in Irrigation Projects

Cost of Establishing Irrigation Projects. What to count as costs for establishing an irrigation project has a significant impact on the economic returns of the investment. The essential point is to ensure that the benefits that are counted be related to the costs that are incurred. Incompletely including one or the other does not provide a correct estimate of net economic benefits.

There is general agreement that establishment costs for irrigation projects should include all costs related to preparing the project as well as to investments in the physical infrastructure itself. This includes such things as preliminary planning and feasibility studies, expatriate management and consultants, engineering surveys and the full cost of equipment used in construction.

Costs for related infrastructure are a different matter. In terms of the economic, as opposed to the financial cost of establishing irrigation projects, one has to question the correctness of including significant amounts of investment in infrastructure without including all of the benefits that occur because of those investments. For example, resettlement of displaced households in better housing than what they left is not necessary. To the extent that such housing is better, the project realizes a benefit (improved housing that would not exist without the project) that offsets the added cost. Roads that give a perimeter access to markets usually improve access for nearby villages and households as well. The irrigation project cannot usually capture those benefits. Such benefits, though indirect with respect to the project in question, are nonetheless real. They should be counted in the benefit stream of the project when they are significant. Power lines, water supplies, storage facilities, and social and administrative services are examples of other infrastructure investments that frequently benefit a larger population than that directly involved in the project. To the extent that this is true, a correct economic analysis requires that costs for these components be reallocated, or benefits increased, so as to reflect these indirect effects. Failure to do so yields an incorrect estimate of the economic value of a project.

A second reason for being careful when including infrastructure costs with establishment costs is the site specific nature of such costs. They distort average cost figures if not separately itemized and, as a result, aggravate cost management problems. They also present the opportunity for policy makers to use the possibility--as opposed to the likelihood--of such benefits as a justification for proceeding with an otherwise uneconomic project. Keeping infrastructure costs separate from actual establishment costs increases the scrutiny that all components of the project are likely to receive.

Crop Production Costs. Crop production costs include all variable costs of production such as water delivery, field machinery services, land preparation, seed or plants, fertilizer, plant protection, transport, fuel, labor and food given to hired laborers. Marketing costs should also be included or itemized separately.

Rarely do planners overlook or not realize the amount of direct crop production costs associated with irrigation. Almost by definition, a transaction occurs during the cropping season for which someone must make a payment. Even where inputs are fully subsidized by the project, some entity is charged with purchasing them and making them available to farmers.

Inputs that are taxed or subsidized by an entity outside of the project are a different matter. It is not uncommon for project analysts to fail to remove taxes paid on fuel, to fail to shadow price foreign exchange so as to reflect its real value to the economy or to include subsidies on fertilizer and plant protection materials in input costs. Agency and management costs such as staff salaries, expatriate management and extension support are other frequently overlooked items that need to be included where these are clearly attributable to the project.

On the other hand, where overhead costs reflect social policy that has nothing to do with the needs of a project for staff, then one can legitimately raise the question of whether excess personnel reflect a cost of managing the irrigation system or as cost of government social policy. Incorrectly attributing such costs to the irrigation project may only succeed in rejecting the irrigation project without avoiding the excess personnel costs since they will in all probability, be assigned somewhere else in the system. What one really wants is a with versus without project comparison. This requires a great delay of judgement concerning government policies that influence how the project will be executed, but which are not essential (indeed, may be inimical) for attaining its objectives. This opens up the likelihood of substantial but legitimate differences of opinion as to the economic value of a particular project.

Assumptions regarding yields and cropping intensity on the one hand, and crop production costs on the other, are another source of legitimate difference of opinion. Higher yields allow production costs that are relatively fixed per unit area, such as land preparation, water delivery and application of plant protection materials, to be spread over a larger number of units of output. Higher cropping intensity allows those production costs that are relatively fixed per unit of time, such as system management, extension and amortization also to be spread over more units of output. Both factors lower unit costs of production and increase net revenue. Project designers frequently utilize favorable assumptions regarding yield or cropping intensity to help justify irrigation investments. The line between realistic expectations for improvement and wishful thinking is a fine one, especially where measures for improving such factors are included in the project design.

Subsidies, Taxes and Price Supports. Subsidies, taxes, import duties, price supports and a wide range of other policies cause the price paid for inputs by a farmer, or the price received for the output, to not reflect fully their real cost or benefit to the economy. Without a doubt, these costs are more frequently overlooked in appraisals of irrigation projects than any other component of costs. Fuel and fertilizer subsidies, cheap credit, subsidized tractor hire or animal traction equipment, taxes or subsidies on imports of competing outputs--sometimes working at cross purposes with each other--complicate the analysis. Sometimes, the only honest thing to do is to assume that such complications cancel out each other. A study on rice production in West Africa, for example, came up with over 20 different ways of producing rice in Ivory Coast and nine different ways in Mali, each of which has its own set of economic costs as the input vector changes (Pearson, Stryker and Humphries, 1981). Doing a complete analysis for one project but not others may result in the better project being rejected, not on the basis of inherent economics but because its analysis is more rigorous. Shadow pricing and economic analysis is one area where a little is frequently worse than none at all. Seldom will the opportunity arise for expanding the appraisal beyond the immediate project in question.

Some subsidized costs are particularly difficult to evaluate. Should equipment donated for a particular project be treated as a free good or valued as though it were purchased? Donors, of course, generally would like to see it valued as highly as possible. Recipient governments, on the other hand, recognize that in the absence of the project they often cannot keep the equipment running. More frequently, they view it as a gift unless they have to pay hard currency for it. Recipients look at what they receive for what they put out, not at the return on the total investment. They generally recognize that future aid flows seldom depend on how well a given investment performs. Foreign aid for development purposes is not a constraint. Managing that aid is. What, therefore, is the appropriate economic value for such inputs? There is no easy answer.

Valuing output in the presence of taxes and subsidies is also tricky. What is the value of sorghum or millet when a duty or quantitative restrictions on imported rice or wheat keeps their price above what it would be in a competitive market? What is the value of any food crop when restrictions on imports turn it into a untraded commodity? These are all questions of judgement, not fact. Their answers will sometimes have a substantial impact on the calculated benefit stream of a project.

Irrigation Investment Costs in Africa

In looking first at reported costs for establishing irrigation projects in Africa, a study commissioned by the Federal Government in Nigeria (PRC, 1982) makes an initial observation which applies to other areas of the continent:

> Because few large-scale projects have been completed and placed in service, there is very limited actual experience with irrigation costs in Nigeria. What experience there is has not been particularly promising, as actual costs often have exceeded planning estimates. (PRC, 1982:25)

Africa is one of the most expensive areas of the world for doing irrigation development. Tables 43 and 44 contrast typical ranges for capital costs from the well-established Asian irrigation sectors with those in the Francophone countries of West Africa. These data suggest that costs in Africa are a multiple of those in Asia.

TABLE 43

TYPICAL RANGES OF CAPITAL COSTS IN NEW ASIAN IRRIGATION PROJECTS
(US /$ha)

Country	Small-scale Communal Projects	Medium and Large Projects
Indonesia	800	1,500 - 3,000
Korea	4,000 - 7,500	8,000 - 11,000
Nepal		2,000 - 6,600
Philippines	500	1,000 - 2,500
Thailand	50 - 500	1,500 - 3,000

Source: Leslie Small et al. (1986), "Regional Study on Irrigation Service Fees," Sri Lanka: IIMI for the Asian Development Bank, p. 20.

TABLE 44

ESTIMATED CONSTRUCTION COSTS FOR FULL CONTROL IRRIGATION IN FRANCOPHONE WEST AFRICA (1985)
(US $/ha)

Type of Surface Irrigation	Earth-works	Concrete	Land Leveling	Pumps	TOTAL
VILLAGE SCHEMES					
River terraces	1,000	700	-	1,500	3,200
Lowlands	2,600	1,800	400	1,000	5,800
LARGE SCHEMES					
River terraces	2,400	800	400	1,200	4,800
Lowlands	4,600	1,200	1,600	1,000	8,400

Source: FAO, 1986; Irrigation in Africa South of the Sahara; FAO Investment Centre Technical Paper 5; Food and Agricucultral Organization of the United Nations; Rome; p. 42. Cost figures are based largely on Mali experience.

These figures may understate the total difference since implementation of an irrigation project in Africa frequently requires substantial infrastructure element (roads, staff houses, crop storage electricity, etc.) not included in the above figures. A recent World Bank review of Ghana, for example, found that some projects have costs as much as $40,000 to $50,000 per hectare (FAO, 1986), though this cost includes an array of social amenities that it may not be appropriate to attribute to the irrigation project alone. The 1986 FAO study also notes that the costs in the Sahelian countries have been among the highest in sub-Saharan Africa, but this, too, is misleading. The Sahel figures are not particularly high in comparison to recent projects in Nigeria, Kenya or Tanzania. For example, Toksoz (1981) gives the investment for Kenya's Bura West irrigation settlement as over $25,000 per hectare (in 1980 prices). They appear "high" when contrasted against the official World Bank estimates of irrigation cost for its large Sudanic projects, where size and a uniform topography generate genuine economies of scale. Almost everywhere else in Africa today, irrigation is expensive, costing from two to five times what a comparable investment in Asia would require.

A frustrating aspect of official figures available on irrigation costs in Africa is that they are frequently not comparable to each other and often substantially below the real costs. Some include staffing, expatriate management, consultants' surveys and infrastructure costs while others do not. As Brondolo observes about the Sahelian schemes:

> Cost overruns have affected all projects... Cost overruns were primarily attributed to changes in design, misallocation of materials and labor, higher than expected rates of inflation and construction delays. Construction delays, in turn, resulted from faulty engineering surveys, the lack of technical skills in rural works construction, cumbersome administrative procedures and intermittent funding by local implementing agencies. (Brondolo, 1985:7)

Maurya and Sachan (1984) provide similar reasons for the high costs of Nigeria's large-scale schemes. They observe that there have been "frequent breakdowns, long gestation periods, cost escalation and underutilization." The actual investment costs for Nigeria's more recent schemes have been nearly double the initial estimates (Table 45).

Understatement of the true costs of irrigation in local settings can take may forms:

- A persistent tendency to undervalue or even overlook existing production on lands scheduled for irrigation development;

- Omission of preliminary planning costs, which often have a large foreign exchange content;

- Carryover in planning documents of outdated cost estimates, without adequate allowance for inflation and deteriorating terms of trade;

TABLE 45

PLANNED VERSUS ACTUAL INVESTMENT COSTS
ON NIGERIAN SCHEMES

Project	Investment Costs (N/ha)[1]	
	Plan Estimate	Apparent Actual
Sokoto, Phase 1	6,400	13,500
Kano, Phase I	4,200	5,100-7,400
South Chad, Phase I	4,300	7,600-10,500

Source: PRC (Nigeria) Ltd.; 1982; A Study of Cost Recovery Strategy for Irrigation Projects. Final Report; p. 26.

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[1] All costs and returns estiamted in 1979 Naira.

- Failure to allow for the impact on costs of construction delays, which are widely encountered in Africa;
- Failure to incorporate assumptions for equipment life that reflect the actual experience of other irrigation projects in the country;
- Omission of the costs of drainage or of field leveling, under the false assumption that these can be provided by farmers;
- Omission of resettlement costs, where irrigation development will require removal of present landholders;
- Exclusion of basic infrastructure costs (housing, power, roads, etc.);
- Failure to recognize that where water is scarce, its deployment within irrigation can have a high opportunity cost; and
- Not allowing for the difference between the targeted command area of a project and the actual area irrigated.

The critical point is that these sources of cost understatement are typical and cumulative: estimation errors on one component are likely to compound rather than offset errors made elsewhere.

When some (though not all) of these are incorporated to give a realistic estimate of actual scheme costs, the low cost-effectiveness of much of current African irrigation becomes apparent. For example, when the Kenya Ministry of Agriculture and Livestock Department totaled up what its Turkana irrigation schemes had cost since the Ministry's first official involvement in 1966, the per hectare costs came to about $63,000.[1]

Significant policy questions arise, then, as to which costs are appropriately attributed to irrigation investments. It is also important to determine whether such high costs are intrinsic to African irrigation or whether, by better design and more attention to cost control, they might be lowered substantially.

FAO (1986) contrasts the cost of selected items used in irrigation construction between various African countries and India (Table 46). Clearly, inputs tend to be substantially more expensive in Africa than in Asia.

TABLE 46

COMPARATIVE CONSTRUCTION COSTS, AFRICA VERSUS INDIA (U.S. $/unit)

Item	Mauritania	Burkina Faso	Niger	Cameroon	Malawi	India
Cement (t)	200	120	140	105	115	80
Steel (t)	2,300	1,090	760	850	1,000	560
Diesel (l)	0.45	0.55	0.45	0.36	0.60	0.32
Unskilled labor (man-day)	2.50	2.20	2.20	8.00	0.43	1.35
Civil engineer (year)	10,000	10,000	10,000	12,500	4,600	2,700

Source: FAO (1986), Irrigation in Africa South of the Sahara, p. 43.

[1]Cost data from unpublished FAO figures. These figures are high because of the remote location and small size of the projects. Normally, costs in Kenya are lower than for similar projects in neighboring countries.

Differences in materials costs are reinforced by other factors. Among those which make African schemes more expensive have been:

- Location of irrigation at remote sites, requiring substantial infrastructure and transport investments.

- Poor quality of construction, leading to completion delays, shoddy workmanship and rapid deterioration of works once put into operation.

- Lack of skilled manpower, necessitating expatriate contracts for specialists and a major training and recruitment program to accompany project implementation.

- High transport costs with high rates of pilferage, breakage and loss.

- Long delays in shipment and clearing, so that most projects come on stream several years behind schedule.

- High local rates of inflation, leading to expensive redesign of project components before the initial design is fully implemented.

- High cost of donor requirements for impact surveys, appraisal missions, etc., all done by external consulting firms.

- Absence of a local service capacity for the intermediate skills and commodities required in irrigation development, all of which must be provided for under project funding.

- Overvalued rates of exchange and high labor costs used in the formal sector.

- Overdesign of structures because of inadequate hydrological statistics, climatic extremes and poor social organization and maintenance within irrigated perimeters.

- Delays occasioned by the donor's employment of conditions precedent to guide loan disbursement.

Once again we note these have a uni-directional impact, all acting to raise investment costs. Furthermore, most are not subject to managerial control. This has often led to tension between the implementing agency and donors, with the implementing agency experiencing costs far above what donors have agreed to provide. Sometimes donors' own efforts to institute tighter cost control have made the situation worse by introducing further delays.

Out of the many reasons for high irrigation costs, six merit particular attention when planning new projects in Africa:

1. The most expensive projects (like Kenya's Bura West, or Madagascar's Morondava Project) seem to have been ones where the

initial design work was either faulty or incomplete, leading to mid-course changes in concept or even rebuilding of scheme works (FAO, 1986). Africa's projects have suffered from numerous technical failures, which are of a nature to threaten the entire production system. Releveling of fields or the relocation of intake structures are bound to be expensive.

2. The quality of contractors' work leaves much to be desired. This either results in physical construction which rapidly deteriorates, or else may necessitate expensive outside supervision of all civil engineering aspects.

3. Construction often takes longer than planned, leading to a loss of several seasons before farmers begin making a profit, and to much higher development costs.

4. The lack of indigenous civil engineering capacity and its high economic (opportunity) cost is undoubtedly a major difference from some Asian experience. (Here, of course, Egypt and the Sudan constitute major exceptions.) When each skilled task (up to and sometimes including perimeter management) calls for external involvement, costs escalate dramatically.

5. The fact that, because of soils and water limitations, the areas actually irrigated tend to be far less than those encompassed by physical works, also contributes to high unit costs.

6. Because of an inability to master the organization of system maintenance, project designers utilize more capital intensive construction techniques and irrigation infrastructure.

We consider it likely that all six of these factors will continue to influence African irrigation costs in the future, at least in the short and medium term.

Recurrent Costs and the Scope for Containment

Recurrent Capital Costs

The high cost of establishing irrigation projects in Africa underlies some of the operational difficulties that typify them. The most obvious is the desire to achieve high levels of cash flow in order to recover investment costs. Take our earlier Nigerian examples (Table 47) showing per hectare costs ranging from 5,000 to nearly 14,000 Naira. At 10 percent interest, amortization over 30 years would require annual payments between 525 and 1475 Naira per hectare (Table 32). According to the authors of the PRC study on cost-recovery strategies for Nigerian irrigation (PRC, 1982), the average net returns per hectare to irrigation under traditional farming are about 432 Naira, not adjusting for subsidies and excluding water delivery costs. Thus without intensifying production, returns do not allow recovery of the capital costs of most

TABLE 47

ANNUAL CHARGES TO REPAY INVESTMENT COSTS
ON NIGERIAN SCHEMES
(N/ha/year)

Total Investment Cost	Equivalent Annual Cost at Varying Discount Rates[1]					
	50 Years Repayment			30 Years Repayment		
	10%	15%	20%	10%	15%	20%
5,000	504	751	1,000	530	762	1,004
7,000	706	1,051	1,400	743	1,006	1,406
10,000	1,009	1,501	2,000	1,061	1,523	1,008
14,000	1,412	2,102	2,800	1,485	2,132	2,812

Source: PRC (Nigeria) Ltd. (1982), A Study of Cost Recovery Strategy for Irrigation Projects. Final Report, p. 30.

schemes, much less water delivery costs or subsidies. The conclusion, supported by farm models, is that where farmers put a realistic value upon their labor, capital intensive irrigated farming does not begin to pay until it has been highly commercialized. Such farming can generate profits required to support irrigation if investment costs are restrained, but it means farmers must use purchased inputs, and must engage in intensive production.

FAO (1986) compares the cost of three typical "scenarios": (1) an irrigation project that is planned and constructed in five years, reaching 50 percent output in year six and 200 percent in year eight; (2) investment spread over eight years with output exceeding 50 percent by year eight, rising to 100 percent at year twelve; and (3) a one-year investment (e.g., small-scale pump schemes) with full production by year three. As FAO notes, option (2) "represents projects as they often are in reality" (p. 157). The study then calculates the amount of incremental production needed at full development to generate economic rates of return at the seven percent and 12 percent levels, worked out with regard to various per/hectare investment cost levels. The study translates the net value of incremental production into an equivalent crop output (t/ha) for paddy, maize, sugarcane and seed cotton.

The FAO results support and extend the conclusions of the PRC study. First, there is little difference between scenarios (1) and (2),

[1]Assumes constant discount rate and uniform payments.

suggesting that construction delays are not critical--provided that costs remain the same (which they seldom do). Second, the incremental production needed to recover investment costs in the range of Africa's more expensive schemes--say $10,000 to $15,000 per hectare--is very high. Not counting the amount required to recover direct crop production costs for operating and maintaining the irrigation system, the net incremental tonnage required to amortize an investment of $10,000 per hectare would be around 6.5 tons of paddy or 8.0 tons of maize at an ERR of seven percent (FAO, 1986). Working in reverse, the study calculates the maximum capital costs that could be supported from somewhat optimistic levels of crop output and crop production costs.[1] It indicates that, for both maize and paddy, investments of more than $5400-$6000 per hectare in large-scale systems become uneconomic at a seven percent ERR. Small-scale pump schemes could support a slightly higher investment ($6600-$6800) using the same assumptions. The conclusion from the FAO analysis is that:

> ...even at the better present levels of production efficiency, none of these crops is likely to generate an adequate economic return at investments costs for the irrigation system of more than U.S.$6,000 per hectare. ....Projects with higher construction costs would require either levels of efficiency which have not so far been obtained, or the addition to the cropping pattern of some higher value items--for instance, vegetable crops. (FAO, 1985: 161.)

As the discussion in the section on irrigation investment costs suggests, containing capital costs is not likely to be easy in those countries with poorly developed professional/managerial skills. Moreover, where public and semi-public agencies are responsible for construction, it will require much tighter work discipline than is common for such agencies in most of Africa. Without improvements in the manpower area, donors will continue to rely on expensive outside firms for most of the preparation and construction work. Without changes in work discipline, even capable local managerial and professional talent will be unable to speed the construction phase and minimize pilfering in order to hold eventual debt servicing costs to a minimum. The principal avenue for containing establishment costs, then, is simply to avoid high cost projects.

This being said, one should not conclude that lower investment costs are always preferable to higher ones. Projects requiring greater investment per hectare may also provide better control over water or maintenance, both of which can increase yields and net revenues. The question, as always, is what one gets for what one spends. This depends on many variables besides the type or cost of irrigation system. What we want to maximize is the difference between additional benefits and additional costs.

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[1]Assuming yields of 5.3 tons/ha for paddy, 150 percent cropping intensity and crop production costs equal to 30 percent of the gross value of production.

More effectively organizing farmers offers significant potential for reducing recurrent capital costs arising from overdesign of irrigation systems. Few projects have succeeded in doing this but its great potential for reducing costs suggests that donors and governments would do well to experiment aggressively in this domain. Enormous sums are spent on oversized wells, canals and pumps so as to enable farmers to complete irrigation activities in 12-14 hours. Self regulating flow structures substitute capital for limited management resources but also increase recurrent capital costs. Economic incentives to encourage farmers to irrigate at night and greater farmer responsibility in system maintenance are but two examples of ways to reduce investment in infrastructure while expanding management capabilities.

Two major obstacles to inducing greater farmer initiative and responsibility are: 1) the high level of subsidy on irrigation capital costs and 2) politicians who measure their worth in terms of what they can give farmers, as opposed to how they can help farmers to develop. In many cases, even a complete elimination of water charges would not suffice to induce farmers to irrigate at night or to accept more responsibility for system maintenance. In such cases a capital charge on day time irrigators would add maneuvering room. One thing is certain: there is a price at which farmers will assume greater responsibility. In those parts of the Sub-Continent where water is particularly scarce, and on most private schemes, they already do.

As for the politicians, project planners need latitude to negotiate management and maintenance responsibilities prior to deciding on site selection. Site selection needs to be conditioned on beneficiary farmers agreeing to assume specific and meaningful responsibilities. Without changes of this sort, it is difficult to envision much progress on recurrent capital cost problems.

Recurrent Operating Costs

Problem Areas. Looking at non-capital aspects of recurrent costs, Gray and Martens (1980), reporting on a review of recurrent costs aspects of development programs in the Sahel, identify five problem areas: inputs, farmer participation, the producer price system, technology delivery and project management. To these five areas we would add the problems of resettlement and water use charges.

Gray and Martens explore both those factors that increase recurrent costs unnecessarily, as well as those which reduce revenues--and perhaps recurrent costs as well--in such a way that a project's ability to cover recurrent costs is impaired. Although they look at only three irrigation projects, many of the observations they make about other types of projects apply equally well to irrigation projects. Most of the observations are valid well beyond the Sahel.

Inputs: Improved seed that underperforms traditional varieties, lack of--or untimely delivery of--essential inputs such as fertilizer and plant protection materials, and short useful lives of irrigatio infrastructure all cause the output actually attained to fall far shor of amounts required for economic production. Except for the influence o poor maintenance on the useful life of the irrigation infrastructure most of these factors are beyond the control of farmers at present.

Farmer Participation: For a variety of reasons, not all of whicl are clearly understood, farmers frequently do not plant on time, do noi apply as much fertilizer or plant protection materials as recommended anc do not weed on time as indicated by research results. Explanations range from competition for labor from rainfed crops to unsuitable recommendations, high risk associated with specialization and high preference for leisure. Where farmers must purchase inputs themselves, the high opportunity cost of private capital--in excess of 50-60 percent per year--reduces the optimum level of application from the private point of view. This has the effect of reducing economic output as well.

The Producer Price System: Official producer prices have a pronounced tendency to become distorted in Africa. In spite of the fact that few African governments succeed in effectively regulating producer prices on a broad scale, most feel compelled to continue the charade. Unfortunately for irrigation projects, concentrated production and the frequent isolation of the production area make it relatively easy for governments to control the movement of commodities into and out of the perimeter area. Thus farmers on perimeters often bear a disproportionate share of the effect of price controls.

In addition to controlling crop movement, most African governments use tax and trade policies to influence the price of exported commodities and commodities that substitute for imports. Again, the impact falls more heavily on farmers on perimeters since more often than not, they are compelled to produce export crops or import substitution crops. This can cut both ways, however. Farmers in Senegal and Niger for example, receive well above import parity for their rice. Obviously, that stimulates farmer participation but does not always make for economic projects.

Ability to recover costs is determined by financial, not economic costs and returns. When the official price is below the economic price, farmers do not receive the income needed to cover the costs on which the appraisal was probably based. The country may be making money, but that does not help the farmer unless the amount of cost being recovered is reduced by a similar amount. One of the best ways of handling this problem is by not charging the full cost of system amortization to farmers. This doesn't help the Treasury but it certainly helps to maintain production at more economic levels.

Delivery of Technology: Gray and Martens (1980) argue that failure of the extension function, perhaps more than any other shortcoming, can jeopardize the success of a project. In a refreshing departure from much contemporary writing on this subject, they do not attribute the failure of extension to a presumption that agents have nothing to extend. Rather they point to the inability of extension agents to command farmer respect and to demonstrate clearly to the farmer that they are offering him a superior technology. Irrigation projects in Africa abound with extension agents who spend little time with farmers, who do not themselves understand how to apply the technologies they are supposed to demonstrate to farmers, and who operate in a vacuum with little or no supervision, limited resources and training, and no one who cares whether or not they are even on the job. Really good agents become discouraged. The rest enjoy their salaries (Moris, 1987). The net result is a failure to achieve input-output relationships that are essential to project viability.

Every perimeter has large numbers of individual farmers who regularly attain yields 35-50 percent higher than the average for the perimeter. With a ready supply of inputs and credit, it is difficult to see structural factors as the principal case preventing other farmers from doing the same. Rather, lack of knowledge and confidence play a much larger role than is currently in vogue to admit. It is precisely to deal with these problems that is the <u>raison d'etre</u> of an extension service.

The failure of extension reflects itself in low cropping intensities, poor cropping and irrigation practices, low yields, short life of equipment and excessive system management costs. These lead, in turn, to an inability to cover recurrent costs because output is low and overhead is high. In most cases, realistic assumptions would make the projects demonstrably uneconomic. Planners need to devote much more time to understanding why farmers do what they do, how they can be influenced to do otherwise and how to organize to so influence them. And they need to avoid making large investments until they have answered these questions.

<u>Project Management</u>: According to Gray and Martens (1980), management problems in Sahelian projects arise from the inability of ministry and agency headquarters to respond efficiently to field level demands. Although the public sector frequently assume a great deal of responsibility witn respect to project operations, seldom does it have the manpower, resources or discipline to do an effective job. Excessive centralization takes control from the hands of farmers and perimeter directors without providing a viable substitute. At the same time, it leads to bloated payrolls that reduce, rather than increase, executive capabilities.

<u>Resettlement</u>: Irrigation projects that involve a significant amount of resettlement pose special problems for financing recurrent costs. On the one hand, such schemes create a captive clientele from whom, theoretically, it is easier to recover costs through project controlled marketing structures. But because land settlement is inherently expensive, it often aggravates rather than alleviates cost recovery problems. It transforms the introduction of irrigation technology from being a matter primarily of farmers' choice to one of bureaucratic responsibility. Once farmers enter such schemes, they encounter numerous legal and procedural controls. At the same time, the government finds it must cope with employment of field staff, establishment of a headquarters

unit to manage the scheme, and the development of an information and marketing system for handling the crop. The supervisory agency becomes involved in questions of plot size, village layout, housing loans, house plans, inheritance rules, crop scheduling, land-use restriction, fuel supplies, eviction procedures, and crop marketing. As we have already noted, these are not functions which African civil servants are adept at performing. Rather than improve system performance and cost recovery, government directed resettlement more often does the opposite. This is compounded to no small extent by the fact that even low level civil servants in Africa receive salaries that are several times the annual income of the farm families they are serving.

When farmers pay directly for services actually received, many complications associated with formal schemes are avoided. Farmers themselves decide what crops to grow. The irrigation agency does not require sophisticated cost information, nor need it police crop marketing. Farmers can live wherever they wish, and their use of irrigation water does not restrict their residence or their ability to recover other on-farm investments. Overall costs are considerably lower so that the economic consequences of a poor harvest are not so dire. SAED's small perimeters along the Senegal River provide an excellent example of this kind of situation.

The negative consequences of an overcontrolled, expensive approach to irrigation through organized settlement schemes are sufficiently great that we must question whether such schemes are necessary. Without denying that cost-recovery is a major problem for irrigated agriculture in Africa, settlement schemes will rarely provide a cost-effective solution.

Water Use Charges: By far, the predominant system for assessing water charges in Sub-Saharan Africa is on the basis of area served. This is not as illogical as might seem at first glance. On many schemes all farmers are required to follow the same cropping system and probably have broadly similar needs for water.

Assessing water charges this way, however simple it may be, fails to establish a direct link between water use and costs. It also tends to prevent farmers from adapting their cropping system to their particular soil and resource situation. Without a connection to water use, farmers have a tendency to view payments for water as payment for services not rendered. This increases their readiness to avoid repayment and/or marketing responsibilities when it comes time to pay. It also can add substantially to recurrent costs by encouraging excessive use of water. In projects served by limited supplies of water, such as those supplied by catchment dams, excessive use of water can lead to a reduction in area cultivated. In areas with a great deal of variability in soils, the inability to adapt cropping systems to soil/water availabilities unnecessarily limits farmer incomes.

Solutions. On the basis of the above analysis it should be obvious that the problem of financing the recurrent operating costs of irrigation projects arises as much from the sector's poor economic performance as from excessively high investment costs. Reducing the establishment period for, and the cost of, new irrigation projects will solve only part of the problem. Policy makers will have to deal with broader issues of agricultural policy, sector organization and agricultural institutions before the situation is likely to improve.

First of all, planners need to concern themselves with maximizing the difference between revenues and costs rather than containing recurrent costs per se. In many cases this will require an increase in recurrent cost financing to cover better quality seed, more fertilizer and plant protection materials, more money spent on maintenance of the irrigation system and, in many cases, operating the pumps and water flow devices more frequently in order to improve the distribution of water.

Other actions which offer to reduce recurrent cost problems include:

- reducing the degree of water control where this will lower capital costs more than production;

- avoiding remote sites, which require heavy investments in infrastructure, and unsuitable sites which provide a small command area in relation to investment;

- greater reliance on underground conveyance devices as a substitute for more land leveling for gravity fed systems;

- transferring responsibility for land preparation, farm operations and marketing to farmers themselves, with the irrigation agency playing a supportive and technical assistance role rather than an executive role;

- tight control over agency staffing to minimize overhead;

- adoption of tenurial arrangements which give farmers strong incentives to invest in irrigated farming;

- greater emphasis on perimeter level applied research;

- improvement of credit and input delivery systems so as to reduce as much as possible the role of the public sector and enhance repayment and market discipline.

- strengthening extension by providing annual retraining, technical backup, more involvement with applied research, more farmer involvement in performance evaluations and farmer control over a significant portion of extension agents' salary.

- instituting charges for water based on the quantity and/or time uses rather than on area cultivated.

One thing that is clear with respect to recurrent costs; there are relatively few places where crop returns will support increasing the amount that farmers are required to pay under present circumstances.

Without more enlightened agricultural policies, better management of systems and more intensive production practices, even major progress in containing investment costs will not eliminate this problem.

Choice of Technique and Cropping System: Implications for Cost Recovery

Choice of Technique and Cropping System

Logically, the higher the investment per hectare of irrigated land, the greater must be the net value added at the farm level to amortize or justify economically that investment. A first step, then, in system design as well as project implementation, is to identify which crops and which technologies for producing those crops will guarantee the greatest net economic value added at the farm level from the system. In this sense technology includes both irrigation technology and crop production technology.

Production technologies suitable for one situation will not, in many instances, be the choice of preference for another situation with identical investment costs. Different climates, soils, input costs, farmer experience, farmer organization, market opportunities, manpower availability, public sector organizational capabilities and a myriad of other technical, social and economic factors condition returns to farming as much as does the cost of the irrigation investment. Yields alone--and yields are only one component of net returns--vary by 100-200 percent between irrigation projects in the same country which are essentially identical from the investment cost point of view.

What, then, is the relationship between investment costs and choice of crop? Apart from the general statement that high investment costs require high net value added crops at the farm level, not much. Site specific analysis will be required to determine which crop and which production technology will yield the highest net value added, counting all costs of production. Soils, climate, input delivery systems and markets all play a determining role. A good crop choice for one circumstance may not be a good choice for another.

With this understanding, one can make some observations concerning cropping systems that are generally valid. For one, the ready availability of fertile prairie in the dry areas of North and South America and Australia make it difficult to produce wheat economically using large scale irrigation in Africa. For another, the high water demands of rice and its abundant supply on world markets from countries much better endowed with labor and water resources make it difficult to produce rice economically on large schemes as well.

Improved traditional systems, on the other hand, offer some of the lowest cost methods for producing rice even though their yields are lower than on many large perimeters. McIntire (1981) shows that the net social profitability of the improved traditional irrigated rice systems in Mali comes close to that of the largest systems at the Office du Niger. The larger systems are more profitable only because much of the investment in infrastructure is now treated as a sunk cost. To expand such large-scale irrigated agriculture to other areas of Mali would require new infrastructure that would be, no doubt, prohibitively expensive.

Humphries (1979) found total production costs for rice to be lower for less than full control irrigation systems in Ivory Coast as well. But there the percentage difference in production costs per unit of output was only a fraction of the large differences in investment costs. This suggests that factors other than irrigation investment costs were more important.

Smaller scale systems can produce irrigated rice more economically in Senegal as well, though again, more is involved than simple differences in irrigation infrastructure. Diallo (1980) calculated the economic cost of producing rice on small perimeters near Matam as being from 36-77 percent as much as on large perimeters in the Senegal River Delta, at Nianga and at Dagana. Establishment costs (including buildings and equipment) per hectare for the larger irrigation systems were 4-5 times those for the smaller perimeters. Operating costs, including crop production costs, were higher on the small pump based perimeters with the result that total annual costs per hectare were not that dissimilar. However, the difference in yields, 4200 kg/ha for the small perimeters versus 1500-3400 for the larger perimeters, led to the lower overall cost of production.

Does the same kind of relationship hold for high value crops? A recent Joint American-Nigerien Field Study (Keller et al., 1987) compared the performance of three different types of onion producers in Niger: farmers using a gravity fed, self-regulating flow system covering 250 hectares at Galmi, and farmers using either 3.5 horsepower motor pumps or manual systems for drawing water from surface and subsurface water sources in nearby areas. In all cases, farmers irrigated less than .5 hectares of land each.

Establishment costs for the large perimeter amounted to ten million FCFA ($34.000) per hectare[1], including a reservoir for impounding surface water runoff that amounted to $13,500 per hectare. Apart from the dam, no significant infrastructure was charged to the project. Farmers using motor pumps, on the other hand, had invested between $375-$3100 per hectare for pumps and wells, depending on whether they had a surface water source and how efficiently they used their pump. Farmers using hand pumping had an average investment of only $160/ha.

Operating costs showed the opposite pattern. Farmers on the perimeter were charged only for operating costs for the system. Since there were no pumps, these were only $73 per hectare for the onion crop--very low for Niger. Farmers using the motor-pumps had pumping costs ranging between $450-$1800 per hectare, including depreciation and interest. The variability depends on how efficiently they ran their pumps and whether or not they had to dig wells to access water. Farmers using manual pumping methods had pumping costs ranging between $1250-$3200/ha, depending primarily on pumping depth.

Table 48 summarizes results for four typical situations, including a low and medium level of efficiency for the motor pump. The large majority of motor pump owners were operating their pumps at very low throttle, lifting water around three meters and cultivating plots under .5 hectares. This increases both fixed and operating costs per hectare over what they would be with higher rates of use.

Table 48 demonstrates that average returns to labor, generally accepted as the most relevant measure for African farmers, are highest for the moderately efficient motor pump system, i.e. irrigated .80 hectares at 3.5 liters per second of flow, drawing water from five concrete lined, open wells per hectare. Not many farmers operate at this level of efficiency. Those that do, earn 10 percent more per day than farmers on the perimeter, after covering all their pumping costs. Farmers using the low-efficiency motor pump systems earn less than farmers on the perimeter, but still earn well above the agricultural wage of 500-600 CFA. So do farmers using the manual pumping systems.

The important point to note is that farmers on the perimeter pay nothing toward capital costs whereas the others pay all of theirs. Indeed, to cover just a modest 10 percent per year opportunity cost of capital and depreciation, assuming a 30-year life for the reservoir[2], farmers on the perimeter would need to generate a return per day more than 70 percent above what they were actually earning.[3] On a full cost basis, therefore, even the manual pumping system provides returns to labor that are more than twice as high as those on the perimeter.

This case study demonstrates several aspects of irrigation system economics that influence cost recovery and that make it difficult to generalize based on unidimensional measures. The gross revenue per hectare of the non-perimeter systems is about 50 percent higher than for perimeter based farmers. This arises from higher yields and higher prices resulting from the better timing of harvesting that a greater control over water and inputs offers. This higher gross revenue substantially offsets their 45-75 percent higher production costs. To be sure, many non-perimeter farmers would jump at a chance for a plot of land on the perimeter. But that arises from the fact that costs on the perimeter are heavily subsidized rather than inherently lower.

The important public policy issue is whether the expensive system was the best way to develop irrigation or to produce onions. In this particular case, there is an abundant supply of land with a shallow water table that permits significant expansion of the shallow well systems--

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[1]In 1984 FCFA converted at 300 FCFA/$U.S. FCFA per day.

[2]Other surface dams in the area have required raising after 20 years because of siltation of the reservoirs.

[3]Assuming 1.7 crops per year on the average.

TABLE 48

COMPARATIVE FARM LEVEL RETURNS
FOR IRRIGATED ONION PRODUCTION
IN NIGER, 1987

	Quantities/Values Per Hectare			
	Irrigated Perimeter	Motor Pumps		Manual
		Low Eff.	Med. Eff.	
Investment Costs:				
Perimeter	10,000,000	-	-	-
Motor Pump	-	300,000	113,000	-
Wells	-	634,000	423,000	48,000
Sub-Total	10,000,000	934,000	536,000	48,000
Capital Costs:[1]				
Depreciation:				
Well	-	63,800	42,300	48,000
Pump	-	37,500	21,100	-
Interest (@ 50% p.a.):				
Well	-	158,500	105,800	12,000
Pump	-	75,000	28,200	-
Sub-Total	-	334,800	197,400	60,000
Yields:				
Onion bulbs (kgs)	38,000	45,000	45,000	45,000
Onion tops (bags)	82	98	98	98
Total Revenue (000)	1,039,200	1,535,000	1,535,000	1,535,000
Variable Costs:				
Pump & Well Operation & Maintenance[2]	-	209,000	117,500	453,000
Other Non-Labor Inputs	300,000	309,200	309,200	309,200
Labor Inputs	467,000	483,400	483,400	483,400
Irrigation Assessment	22,000	-	-	-
Sub-Total	789,400	1,001,600	910,100	1,245,600
Returns to Capital and Management	249,800	533,400	624,900	289,400
Charge for Invested Capital:				
Depreciation	-	101,300	63,400	48,000
Interest (@50% p.a.):				
Pumps & Wells	-	233,500	134,000	12,000
Other Non-Labor Inputs	-	51,500	51,500	51,500
Sub-Total	-	387,300	249,700	111,500
Returns to Management	249,800	146,100	375,200	177,900
Man-days of Labor Required[3]	672	740	740	1,462
Return Per Day[4]	1,067	873	1,183	760

[1]Assuming one crop per year for the non-perimeter systems, using Nigeria prices. Virtually all farmers purchase field equipment and pumps from Nigeria.

[2]Assuming average pumping depth of three meters. Includes labor associated with pumping and well maintenance. Average labor requirement for manual pumping systems in 1500 hrs/meter of lift.

[3]Includes labor includes motor pump operation.

[4]Equals the sum of the labor component of pump operation and maintenance, labor inputs and returns to management divided by man-days of labor required.

Source: Keller et.al, 1987.

certainly much more than the 250 hectares developed by the project. Development of the perimeter proceeded because of a lack of vision by donors and policy makers with respect to alternative methods for developing irrigated agriculture in Niger. During the design phase only PVOs were actively encouraging expansion and development of the improved small scale technologies.

The very high returns available from producing onions at Galmi allowed donors and planners to justify the very high costs of the system. Assuming a double crop of onions and no reduction in command area due to siltation of the reservoir, they had little difficulty attaining a positive rate of return. According to a recent field study in Niger, more reasonable assumptions based on modest improvements in cropping practices established thus far suggest an economic internal rate of return no greater than zero. But the main problem was not the rosy assumptions; it was the failure to consider alternatives--the limited vision of the persons who conceived of the project and pushed it to the point where the principal remaining question was whether it was economic.

The choice of crop is also instructive. Farmers near Galmi have a regionally recognized reputation for producing quality onions. As a consequence, they receive a flush season price that is 33 percent higher than that received by farmers at Say, 350 kilometers closer to Niamey and Abidjan, key marketing points. If farmers on the perimeter received the same price as farmers at Say, their gross revenue would decline by 250,000 CFA, returns to management would evaporate and the average return to labor would fall under 700 CFA per day. At that price for onions, other crops such as cotton, millet and cowpeas would offer more attractive average returns to labor than would onions. Thus a high value added crop in one situation may not be a high value added crop in another situation.

Not uncommonly, project planners select and impose a cropping system based, not on economic returns, but on the extent to which the crop facilitates cost recovery, or fits into a larger macro-economic context. Cotton, oil seeds, and to a lesser extent, wheat and rice, lend themselves to cost recovery because farmers usually do not consume them directly in large quantities. Moreover, non-project marketing opportunities may be limited or effectively controlled. Frequently, farmers themselves support this approach as long as it leaves them some flexibility and the freedom to grow food corps or other crops of their own choice at some point during the cycle. This is a factor that is little appreciated in much of contemporary writing on irrigation. On the other hand, examples abound where farmers are required to produce crops that provide returns that are inferior to readily available alternatives. This becomes a serious problem where such crops consume a large proportion of a farmer's available resources.

Cost recovery is a problem in Africa first and foremost because returns to a farmer's own resources are frequently only marginally better than for non-project alternatives, even after allowing for the dry season employment which irrigation provides. But, it is also a problem because, as with credit programs, farmers frequently get away with not paying.

Only recently is it becoming widely acceptable to remove farmers or deny them access to water for not paying their share of operating expenses. This is a factor independent of the level of returns; though it is certainly true that low returns make a farmer more willing to risk being denied water or other services.

Pressing needs for cash make it difficult even for farmers with good intentions to hold onto their revenue until it comes time to repay. Farmers recognize this and, in general, do not oppose having charges deducted at the point of sale--provided the opportunity for selling is not unduly delayed and only enough crop to cover production costs is required to be sold. Farmers recognize that cash is a very poor store of value in low-income traditional settings; but they also do not like getting ripped-off on their entire crop under the guise of cost recovery. This, more than anything, drives them to sell in parallel markets and aggravates problems with cost recovery.

Methods for Recovering Water Costs

The method for recovering water costs is an issue throughout Africa. Allocating water costs on the basis of area cultivated does not encourage conservation, but it is easy to administer and is relatively incorruptible. Any system that relies on measurement as recorded by a person is subject to manipulation or lack of enforcement if the water keeper does not take his responsibilities seriously--not infrequently the case. If farmers were allowed to group themselves into sectors or sub-sectors on the perimeter, then rates and times of flow could be used to allocate costs. But to succeed, such a system would probably need to be based on a set of weights that total to a constant sum. In this way one group's charges have an impact on what others pay. With an open allocation system based on a monthly general meeting, one could count on the competing interests of the different groups of farmers to keep the system honest. Obviously, the individual groups of farmers would have to be relatively small and cohesive before such a system would lead to significant water conservation, since they would still have to find some way to allocate costs within the group.

Finding viable methods for recovering water costs that also encourage conservation of water is one of the greatest challenges facing irrigation in Africa today. Methods that work in Asia will probably not work in many places in Africa. But African farmers have faced collective resource allocation problems for centuries. In many cases they have developed well accepted social structures for resolving such conflicts. Project designers who are serious about cost recovery and conservation of irrigation water would do well to involve farmers in the decision on how to allocate the costs. To be effective this should be done before the design or the location of the project are finalized. Once the perimeter is installed, the flexibility needed to obtain a resolution of such issues is greatly reduced.

Designing and Appraising Irrigation Projects: Some Procedural and Methodological Notes

The large number of poorly functioning irrigation projects in Sub-Saharan Africa suggests that the procedures and methodology used to design and appraise such projects are not sound. In spite of initial estimates of 20+ percent economic internal rates of return, *ex-post* analyses reveal few projects that remain positive under the compromises and realities of implementation. Partly, the problem arises from the inability of farmers or the irrigation management authority to capture all of the economic benefits for themselves. This requires some form of subsidy which, if not forthcoming in a proper time frame, form and amount, can result in farmer behavior and production levels that differ significantly from those anticipated at the time of appraisal. In larger measure, however, the problem results from the very way in which governments, donors and lenders approach project selection, design and appraisal.

Tiffen (1985) analyzes data from over 50 irrigation projects world wide, eight of which are in Africa. She outlines problems that are common to many of the schemes, speculates as to their cause, and proposes modifications in the project process that would correct them. She lays much of the blame for project failures on excessive reliance on highly unreliable internal rates of return as a unidimensional indicator of potential project achievements. This has led to insufficient weight being given to other socioeconomic and institutional considerations.

In general, Tiffen's analysis is quite complete and insightful. However, she errs, in our opinion, in attributing problems arising from sloppy conceptualization, design and measurement of project effects to the internal rate of return. The internal rate of return measures the mathematical relationship between a stream of costs and benefits over time. It measures with the same precision whether or not the streams are identified and measured correctly. The problem, in our view, is not with the internal rate of return, but with how costs and benefits are identified, measured and scheduled over time. This problem is related, in part, to the way donors and lenders organize their development assistance. This is not to deny certain problems with internal rates of return when they fall well above the opportunity cost of capital. But this problem is well appreciated by most analysts. More fundamental problems lie elsewhere.

Before the design and evaluation of irrigation projects--indeed of all development projects--can improve significantly, donors and planners need to recognize and offset the pressures that lead to poor projects. These are not as much personal as they are professional. By the time a project reaches the appraisal stage, very few of those responsible for giving the go ahead have an interest in reversing course. A donor often will have budgeted for the project on the assumption that it will proceed. It will have set staffing patterns and work programs over the next one to two years based on that assumption. A negative determination upsets that whole process. Moreover, many donors commit funds to an idea before it is even designed. While such commitments are clearly more political than economic, they are, to some extent, necessary so that everyone can plan their lives over the next one or two years. People deal with uncertainty in their professional lives no better than in their personal lives.

Donor agencies also tend to be run by management-by-objectives types; and the objective tends to be money obligated and spent rather than effective development projects. Someone sets objectives and associated budgets. Field staff meet them or explain why they failed to do so. The more removed this management process gets from the grass roots reality that dictates sensible policy, the more the evaluation and decision process is based on management rather than on project or development issues. The whole concept behind such a management approach is that processes can be planned and controlled. Unless the management system is sufficiently flexible to allow adequate time for research and development, and for the festering that is very much a part of good research and development, there is a tendency to move to action before the situation warrants. There is a natural withdrawal from involving beneficiaries in project design because this opens the entire process to a whole range of uncontrollable factors and delays. This is doubly true where there are significant cultural differences between planners and project designers on the one hand, and the people who will implement and benefit from the project on the other. For this reason "participation" often means little more than conducting a reconnaissance survey. Rarely does it mean trying to forge a consensus among project participants, even in social contexts where forming consensus is the predominant legitimizer of group commitment. Donors either assume this process is done by the host country or conveniently ignore the fact that it is not done or is done superficially.

With respect to the actual design process, an OCDE (1985) study makes some cogent observations:

- In the case of multipurpose hydraulic projects, the final shape of the waterworks is the result of a long process, involving a number of decisions at various stages of the project. At the same time, those decisions are not taken by one decision-maker. Rather, they emerge as the only possible result of negotiations conducted between the various group interests involved in the project.

- At the beginning, the project is only a vague preliminary idea. If some of the major beneficial effects are in general contemplated (and often, overestimated), most of the possible adverse effects are ignored...

- It is important to notice that...the crucial step for a hydraulic project is seldom the feasibility study. Most often, it is the time at which a permanent team is recruited to proceed with detailed studies. Before that stage, it is always possible to abandon the project (OCDE, 1985:13-15)

The OECD study goes on to emphasize the need to plan public participation and to start the social investigation at the inception of the project.

Tiffen (1985) identifies several socioeconomic and institutional problem areas of irrigation schemes. Some of the specific ones that pertain to sub-Saharan Africa are:

1. Non-project activities that compete with the irrigation project for resources.

2. Agricultural marketing and pricing policy.

3. Availability of farm labor.

4. Tenure and settlement issues.

5. Conflict between government and farmer objectives.

6. Inadequacy of resources for system operation and maintenance and for on-farm development.

7. Staffing.

Tiffen (1985) cites a study done by the International Institute for Land Reclamation and Improvement (ILRI) that urges greater attention to how projects fit into existing social, institutional and farming systems. The FAO Investment Centre (1986) in its review of irrigation south of the Sahara identifies somewhat similar problems, again emphasizing the need for institutional and design changes that are better adapted to local capacity for operation and maintenance. Yet, in spite of the chronic and continuing nature of these problems, donors and project designers continue to put the greatest emphasis on technical considerations in project development.

What Tiffen, FAO and the ILRI are essentially recommending is that the design process be reversed. Rather than begin with the design of the irrigation system based on what is technically optimal, they should begin with the participants and institutions responsible for implementation. Only after the strengths and weaknesses of each of these have been identified and the incentive structure clearly understood, should technical design begin. That process then can proceed in iterative fashion as governments and farmers decide which changes they are willing and able to make and what impact that will have on farmer participation and project execution.

With respect to appraisal methods it is quite clear that the economic analysis, whether based on internal rate of return, cost benefit ratios or net present values, should not be the dominant criterion for deciding important design issues. The economic analysis only measures the net result of all of the design and implementation assumptions used in preparing the project. Changing one of those assumptions may improve the apparent rate of return. But only effecting the assumed change will alter the actual rate of return. Thus, first and foremost, design considerations should center around what is feasible and acceptable to government and farmers and what impact this will have on project performance. If that results in a positive economic outlook, fine--the project may be a winner. But if it does not, then changing the assumptions will not improve the project.

The multitude of factors affecting realized project output explains much of the honest difference of opinion with respect to choice of cropping patterns, techniques of production and input-output assumptions to use in evaluating the potential economic impact of proposed irrigation projects. In such a context project design and evaluation requires the input of social scientists as much as, if not more than, engineers and agronomists. Even with this perspective, planners must still decide whether to use the recent historical performance of similar schemes as an indication of likely outcome, or to expect an improvement based on provision of additional services or policies designed to overcome problems with existing systems. How will these improvements work in practice? When all is said and done, project planners usually opt for optimism rather than "cynicism" and assume significant improvement in performance.

There has been enough experience with irrigation in Sub-Saharan Africa, and there is enough similarity in cultural context and experience with technology across the Sub-Continent, that we can say with confidence that planners who ignore previous performance are generally making a mistake. We cannot say with a great deal of confidence why African farmers respond the way they do; but, as indicated previously, we can predict with considerable accuracy how they will respond. In general, they will not plant at the optimum time, they will not weed as often or as timely as required, and they will not apply the quantities of fertilizer and/or plant protection materials recommended by technical scientists. Whether this is due to poorly conceived technical packages, farmers' unwillingness to give lower priority to traditional food crops, an opportunity cost of private capital in excess of 50 percent per year, or a lack of trust in the ability of the system to deliver necessary inputs on time and in suitable condition are open questions. We are much more sure that, unless a causal factor is correctly identified and effective action taken to overcome it, new schemes will not perform significantly better than established ones.

What are reasonable input-output assumptions to use when analyzing the economic impact of a project? In Niger, perimeter wide average yields of paddy range between 2600 and 4800 kgs/ha, with new schemes often attaining in excess of 5000 kgs/ha. In Nigeria, planning figures used for major irrigation projects range between 3500 and 5000 kgs/ha for maize, 2500 and 3600 kgs/ha for wheat and 2800 and 5500 kgs/ha for paddy. Also in Nigeria, fertilizer has been subsidized as much as 90 percent over the past five years. In Senegal, fertilizer subsidies no longer exist. Cotton farmers throughout most of Francophone Africa do not pay directly for plant protection materials. In Sukumaland in Tanzania they do. Do we expect to see similar yields under these differing circumstances? Of course not. We will not, therefore, see equal returns to investments in irrigation.

Anyone who has done an actual appraisal can attest to the difficulty in ascertaining just what is feasible in a particular context. Not only do project designers have to solicit the views of farmers and executing institutions, they also have to understand and appreciate what they are saying and what they mean. This is no small task when such significant cultural differences exist between designers and users--even assuming language is not a problem. Only by helping countries to develop an indigenous capacity for project design that includes meaningful participation by all project participants is the project design and appraisal process likely to improve on a sustained basis.

None of this precludes fudging numbers so as to obtain an acceptable rate of return. But, to be fair, we must acknowledge that the difference between fudging and optimism is a fine one. To overcome such problems the appraisal should include a sensitivity analysis of alternative outcomes. Without a doubt, one of those outcomes should be what is currently being attained by similar projects in the country under the assumption that policies and institutions do not change. Experience, in fact, suggests that this scenario is indeed the most likely outcome regardless of intentions to modify policies or alter institutions.

Up to this point our analysis has assumed that donors, consultants and government officials involved with irrigation projects are motivated to do what is best for the country where the project is located. Unfortunately, this is all too frequently not the case. Donors tie their aid to suppliers from their own country, even when the products and services being provided are demonstrably inferior or unnecessarily costly. Consultants can have secret arrangements with suppliers or contracts that result in commissions for long term employment. Government officials can extract all kinds of bribes and consideration for their approval. Even the executing agency benefits from having funds to administer, creating plentiful opportunities for individuals to enrich themselves.

Many multinational firms have consulting subsidiaries that do studies relating to products which they sell. Andre and Beckman (1985) note the key role played by IMPRESIT, a Fiat consulting subsidiary, in initial optimistic consulting reports on highly mechanized wheat irrigation schemes in Nigeria. These projects eventually produced wheat costing five times as much as imported wheat. Zalla (1982) criticized an IMPRESIT study which proposed large scale, heavily mechanized irrigation schemes for developing the Juba River Valley in Somalia. IMPRESIT made a series of extremely optimistic assumptions concerning irrigation efficiency, the rate of use and field efficiency of agricultural machinery, input prices, cropping intensity, project implementation, available river flow and the supply of inputs and skilled labor--all of which were required to show that the project was economically viable as designed. According to Zalla, assumptions reflecting a more reasonable degree of improvement, and including all costs, would result in a highly negative rate of return. Clearly, African governments are not out of line when they question the recommendations of "experts" and donors.

Since the greatest number of avoidable problems arise from failure to understand the local economy and factors affecting the income of farmers, project designers need to pay particular attention to farmer incentives, reactions and practices. In Sub-Saharan Africa this should include a careful financial analysis of the returns to the farmer and the managing organization. It should determine whether farmers have adequate assets or credit to make the necessary investments; whether inputs will be available as anticipated; whether farmers have accepted the operation and maintenance roles that are expected of them; whether they have access to the necessary support and marketing facilities; whether farmers are seeking to maximize returns to land, labor, capital or water; and whether farmer organizations need reinforcing in order to assume the added responsibilities expected of them. In addition, designers should determine the size of farmer groups that promises to provide a basis for cohesive action; and determine how this should affect design of farmers' organizations and irrigation infrastructure. They need to determine the kinds of technical assistance and extension support that farmers will need and for how long; how operations and management will be financed and the record of other irrigation projects in this regard; and whether planners have allowed adequate time to insure that farmers understand, agree to, and can effectively implement the actions that are expected of them. If administrative skills are scarce, the project should operate so that farmers and local institutions can make the most of the operating decisions.

All of these things affect the internal rate of return of a project. The important point is socioeconomic studies should be done before, not after the technical design.

All of this discussion on project design must not conceal the fact that good projects come from good implementation. Problems with the initial design frequently can be corrected. This requires flexibility and adaptability--two qualities that tend to be lacking in public institutions in Africa. problems of design. Some would cause but a slight tripping at the start if they were not allowed to continue uncorrected. Slower starts, pilot projects in areas with little or no operating history, more local level participation in physical design would all shift emphasis toward implementation and adaptability.

At the same time, effective implementation will require that national governments, donors and lending agencies be more flexible as well. Where governments cannot be dissuaded from funding operations and maintenance out of general revenues, they should be made to demonstrate that they can deliver adequate funding on time. Alternatively, donors should attach an appropriately high shadow price to recurrent expenditures that are likely to be underfunded or untimely. Donors will need to allow for more flexible, organic and evolutionary predesign study and analysis of socioeconomic and institutional factors. This will reduce their ability to control the scheduling of project design and implementation and will increase the need for continuity of staffing and institutionalizing memory. But in return it will increase their ability to prepare and execute viable development projects.

In conclusion it bears restating that the problem with the appraisal of irrigation projects in sub-Saharan Africa is not so much excessive reliance on the internal rate of return or whatever least common denominator is used to measure the economic effect of a project. Rather, problems arise from the failure to prepare adequately and to conduct a rigorous financial analysis of the final design. Economic, financial and institutional analyses are not substitutes--they are complements. The institutional analysis should reveal whether institutions and individuals have the capacity to respond as expected. The financial analysis should reveal whether they have the incentive to respond as expected. Once the technical design of the project and the policy environment have been adjusted so that it is both institutionally and financially viable, then and only then does it make sense to do an economic analysis. The economic analysis follows the institutional and financial analysis, it does not lead them. It simply measures the net economic impact of what is likely to occur. If project designers, governments or donors do not like what is likely to occur, then they need to alter the design or incentive structure, not the economic analysis. The economic analysis measures the effect, not the cause of problems with design and implementation. Finally, success depends less on the feasibility study than on the sequence of studies and actions leading to implementation, and the adaptation to new evidence that becomes available during implementation.

CHAPTER NINE

IRRIGATION MANAGEMENT

There is a burgeoning literature on irrigation management, mostly derived from Asian experience.[1] Much less has been written about managing African irrigation, though in the general literature there is a consensus that managerial weaknesses are a major cause of low African performance. The traits commonly encountered in African management combine to create "one of the most difficult administrative settings found anywhere in the world" (Montgomery, 1987:913). Some donors regard poor public sector management as the distinguishing feature of African development administration--a major reason for the external pressure to privatize the parastatals which African governments have established to manage agricultural activities like irrigation. Alternatively, there are experts who urge that supervisory agencies devolve operational irrigation functions onto water user associations, again a recommendation based almost wholly on Asian experience (Bagadion and Korten, 1985; Coward, 1985; FAO, 1982; Uphoff, 1986). However, African schemes differ in many respects from the large wet-rice Asian systems, just as African economies also differ from Asian ones. These differences make it questionable that "privileged solutions" like privatization or devolution will bring automatic increases in irrigation performance (Moris, 1987). When weighing policy changes intended to improve irrigation performance, it becomes vital that analysts understand how African systems actually operate.

Reconceptualizing Irrigation Management

Managerial Scope

Essentially management consists of an integration of diverse activities to achieve an agreed goal. In developed countries where irrigation is well established, most analysts see irrigation management as being primarily concerned with the delivery and control of water. Water is obviously the main physical input, whose augmented delivery to farmers' fields defines the purpose of an irrigation system. Its flow, when traced from source to application and then removal, identifies the components in an interconnected water management system. This is usually seen as divided into two major parts: the storage, conveyance and distributional aspects, dealt with by civil and irrigation engineers, and the on-farm water management, handled by farmers themselves. Irrigation management is then comprised of activities aimed at optimizing the conveyance and productive use of water.

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[1]See Bottrall, 1978, 1981, 1985; Bower and Hufschmidt, 1984; Easter, 1986; Ellman, 1974; Hydraulics Research, 1986; LeVine, 1976, 1977; Peterson, 1984; Plusquellec and Wickham, 1985; Sagardoy, 1982; Walker, 1984; and Wang and Hagan, 1979.

It is not generally recognized that this focus upon water optimization is feasible because farming activities occur within a fully elaborated institutional superstructure. In a developed economy, most allocative decisions at the sector level have been taken. Land use within a catchment is under control. The commercial sector can supply almost any technology desired. There are many contractors able to construct facilities and install equipment. At the tertiary level of the field turnouts, one finds large-scale farmers who can arrange crop financing, land preparation, and distribution of water between individual fields. In an institutionally complex setting like this, the irrigation engineer's advice will concern primarily hydraulic matters derived from the operation of the main conveyance system, coupled with agronomic advice on crop water needs--precisely the two aspects usually identified with the topic of "irrigation management."

The situation faced by irrigation engineers in Africa south of the Sahara requires a wider distribution of managerial effort. There are several differences. Perhaps the most basic is that field managers are supervising the installation of a technology. There are sector level decisions concerning when and where irrigation is likely to be cost-effective. In bankrupt but drought-afflicted economies where most equipment is imported, these are not easy decisions. Furthermore, modern irrigation technologies can be very demanding of the larger system. They imply numerous "upstream" (input) and "downstream" (output) linkages (Walker, 1984): uninterrupted energy supplies, timely access to replacement parts, a backlog of hydrologic data, systems for input financing and delivery, technologies for crop drying and bulking, and a reliable transport system. While these linkages are already operational in a developed country, one cannot assume they are present in remote African environments. The more undeveloped an area (and a country's sociotechnical infrastructure), the greater the amount of managerial effort which must be devoted to technology adaptation and support.

When specialists claim their technologies are proven but the fault in Africa derives from the inadequacy of the larger system, what really is at issue is who should manage the components other than water. This is a genuine problem throughout much of Africa, where the choice of technologies has been bureaucracy-led rather than demand-led. The governmental systems often evidence little technical capacity, and farming has not yet become commercialized. Neither the administration nor commercial suppliers will be capable of assuming the added responsibilities which accompany the establishment of irrigation. Some would say that under these circumstances, irrigation itself should be avoided (the demand-led view of agrarian development. However, few African regimes are willing to forego developing irrigation entirely because the requisite environment for farmer-initiated adoption does not yet exist. With large hydropower projects in the offing, and given the obvious need to combat drought (see chapter one), countries are proceeding with irrigation investments (even when the technologies installed exceed the present institutional capacities). Without having anticipated this responsibility, field engineers responsible for water development must make informed judgments about institutional capabilities in fields far removed from their own specialties. They are also likely to find themselves supervising the construction phase (a time consuming and frustrating assignment where support services are poorly developed).

A second major difference concerns the greater prominence in Africa of water supply difficulties. As chapter two indicated, the combination of high spatial variability in rainfall, marked interannual fluctuations, and a high evaporation rate means that surface water must either be stored over the whole season on substantial catchments, or else drawn from major rivers. Even small structures must be designed to withstand extreme flows while perhaps remaining dry for up to 2-3 years at a stretch. Groundwater is just as problematic over a large share of the continent, being subject to hardrock conditions with only localized fracture zones where water extraction for irrigation is feasible. Overlaid upon the natural problems of rainfall uncertainty, soil salinity, and high sediment loads within river flows are further uncertainties introduced because the economic systems can no longer keep water lifting equipment in operation. Shortages of fuel and spare parts plague rural Africa, having become such a usual feature of the environment that operators routinely hoard supplies and cannibalize equipment for parts. As we indicated in chapter three, water supply difficulties are a constant preoccupation requiring technical help and managerial interventions.

A third difference relates to the attributes of the administrative system itself, the performance orientation of staff and the likely capabilities of the labor force. Analysts who have long experience in Africa find that the administrative systems differ in profound ways from the kind of rational, performance-oriented professional service which can be entrusted to perform technical functions without external supervision (Hyden, 1983; Wiggins, 1985; Leonard, 1987). In an important recent study of senior managers within the nine SADCC countries, Montgomery (1987) found that on the whole a personalistic style of management was predominant, that agencies were more concerned with safeguarding their resources than with jurisdiction or policy, and that officials neither dealt with the public nor even considered development goals as being very important. Many of their problems arose not (as we might have assumed) from public complaints and from client pressures, but rather from the "sheer incapacity" of subordinate staff. Senior managers spent an inordinate amount of time worrying about logistics and "even trivial details of resource management" (1987:919).

A fourth fundamental difference, which concludes our listing here, concerns the generally high levels of uncertainty with which African managers must cope. The managerial input required in a system is largely a function of the amount of discretionary action needed to achieve desired outcomes. Relatively little management is necessary in well structured settings, where existing routines anticipate likely events. In heterogeneous environments, instead, managers must respond to variability, uncertainty, diversity, choice, and complexity (Poh-Kok Ng, 1987). All of these sources of variety are present in any larger African irrigation system: variability in rainfall and prices; uncertainty caused by diseases and equipment breakdown; diversity in soils, crops, and tenure systems; changing farmers' preferences or new policies; and complex systemic linkages backwards and forward to other components in the overall system. These contribute jointly to a high need for discretionary adjustment to attenuate, match or amplify other variables in order to safeguard the attainment of production objectives.

Successful irrigation depends upon schedules: increased flows of water that arrive on time and at predicted place. Because water obeys clearcut physical laws, and plants have known moisture requirements, irrigation engineers have long since worked out irrigation structures--physical and organizational--to cope with the routine variations encountered in a typical command area. As Ng notes, the physical and behavioral structures complement each other; they provide structural decisions which minimize the need for ad hoc decision-making. This reduction in uncertainty is accomplished by physical structures (weirs, canals, turnouts, etc.), by the accumulation of decision rules based on operational experience, by stipulated actions which fall within organizational competencies and can meet particular demands, and by the framing of contingency plans for extreme events. A "well managed" irrigation system should in theory possess an interrelated set of facilities and procedures sufficient to cope with most variations within the larger system (Poh-Kok Ng, 1987).

Such systems, which are usually accompanied by a formal-deductive rationale, work well where the problems encountered are structured and fairly typical. They reduce irrigation management to a set of switching decisions: deciding when and where to activate which predetermined routine. The "management" they draw upon is in large degree sunk capital, the cumulative investment of attention by earlier generations of technicians to devise, test, and improve the structures and procedures which provide control over the movement of water through a physical system.

In Africa, however, the "sunk capital" reflects the efforts of many donors and a succession of external consultancy firms who have advised upon and designed irrigation projects. Boeree (1971) points out how in Tanzania the country's irrigation sector contains major projects designed by FAO, the British, the Chinese, and Dutch advisors--to which one could add in recent years the Koreans, Indians, Sudanese, and Japanese. It is a tradition in much of Africa that senior staff are rotated in and out of different agencies and ministries at will, so that managers may not be familiar with their own organization. Bottom level staff are notorious for their unreliability throughout Africa, with the result that "the most basic bureaucratic functions are performed very poorly" and "managers are overwhelmed with the task of supervising and checking simple tasks" (Leonard, 1987:908). Managers must deal simultaneously with an array of contradictory and overlapping donor requirements, complex and inefficient internal procedures, and a turbulent external environment. While effective African managers do have techniques for coping with such demands, these will take a quite different form from the optimization schedules which advisors accustomed to highly controlled environments typically recommend.

Who Manages What? The term "irrigation management" thus implies a degree of control over systemic components which is not found within many African systems. This lack of isomorphism between the water conveyance and distribution system and the locii of control over various subcomponents is responsible for much analytic confusion. It is paradoxical that most professionals who design irrigation projects, either civil or irrigation engineers, do not subsequently manage them.

Easter (1986) suggests that water resource management for a surface irrigation system typically encompasses six domains, including the management of: 1) the watershed; 2) the reservoir; 3) the canal system; 4) the farming system; 5) drainage; and 6) marketing. A slightly modified outline would give us seven types of on-going activities and one temporary phase (project construction):

- Sector planning and supervision;
- Drainage/river basin development;
- Storage and conveyance ("main system") management;
- Perimeter and scheme management (the distribution system);
- On-farm irrigation (the application system);
- Inputs and marketing;
- Environmental impact management; and
- Project construction (temporary).

This listing puts reservoir management alongside control over water conveyance as the two components of "main system" operation. It assumes that attention to drainage should occur at several levels (conveyance, distribution and application) rather than constituting a discrete component. Environmental impacts are separately identified, because these are a major concern in the tropics and are not confined to reservoir management. Finally, in large projects there is also a need for separate organization and supervision of construction activities.

The focus of this chapter is on the major organizational types which share responsibility for irrigation in Africa. The organizations which will be reviewed are outlined in Table 49 below, in relation to the kind of units they control.

This distribution of managerial functions neglects the question of who will manage environmental impacts. At present in Africa this is a residual concern, left either to the district administration or to concerned outsiders generally residing abroad.

The various activities which may require managerial support are broken down level by level in Table 50 overleaf. It is obviously not practical in an overview chapter to review each of these responsibilities individually, and it is apparent that some might be found at different levels depending upon the particular situation in a given country. For example, some countries aim at uniform, national coverage of the hydrometeorological network while others leave this task to river basin authorities. We stress that there is no single "ideal" distribution of these functions. Instead, the point is that in Africa where farming is done by smallholders, most of them are necessary, and that as a consequence irrigation output depends heavily upon the nature and effectiveness of inter-organizational linkages between levels.

TABLE 49

LEVELS IN AFRICAN IRRIGATION MANAGEMENT

Managerial Organization:	Units to which applied:
Ministry	sector, function
Authority	river basin, drainage
Parastatal	schemes, facilities
Scheme	perimeter farmers
Community	small system, projects
Farmers	fields, application

One can see at a glance from the complexity of this matrix that "irrigation management" should be viewed as a systemic goal to which various units contribute, rather than as a cluster of duties entrusted to a single level. No single profession can supply managers competent to supervise all the activities required when introducing irrigation technologies. The hydraulic components may become priority concerns at the river basin, scheme, and farm levels. But there are other, equally essential interventions at these same levels, and many support actions at other levels. A Ministry of Agriculture which fails to include irrigation requirements in the annual budget can cripple performance just as surely as can an on-scheme cooperative which gives out bad seed or fails to pay farmers on time. The linear nature of agricultural production activities has the consequence that output necessarily reflects the joint managerial performance shown at different levels in the system (Moris, 1981). When we conclude that African management is a "problem," one explanation may be simply that the necessary support interventions which are taken at different levels do not yet intermesh with each other.

Management theory handles such situations as being problems of "matrix management": a term coined to explain the need to coordinate

TABLE 50

IRRIGATION MANAGEMENT RESPONSIBILITIES

Ministry/Sector

Donor negotiations
Five-year plan
Enabling legislation
Liaison to annual budget
Manpower planning
Area/regional priorities
Rainfed vs. irr. priorities
Price policy

Irrigation Parastatals/Agency

Staff recruitment for schemes
Procedural standardization
Equipment standardization
Design standardization
Design assistance to projects
Site feasibility studies
Planning new schemes/projects
Terms of service for schemes
Procurement and inventory for schemes
Loan repayment
Donor negotiations if delegated
Scheme supervision
Managerial contracts for schemes
Construction contracts for schemes
Impact monitoring
Disbursement of recurrent funds
Disbursement of staff salaries
Open external letters of credit
Technical assistance to schemes
Joint training for scheme staff
Engage external consultants
Arrange scheme evaluations
Liaison with agricultural research

Scheme Cooperative (on scheme)

Extend credit to farmers
Collect/store/transport crops
Supply inputs/seeds/pest control
Record keeping on farmers
Cost recovery from farmers
Possible role in extension

User group (if off-scheme)

Agree on water rotation
Maintain supply/headworks
Emergency repairs

River Basin Authority/Drainage

Coordination between countries
Hydrometeorological network
Use of remote sensing
Coordination between projects
Donor negotiations
Dam and power operation
Land and water rights, laws
Project feasibility studies

Scheme/Perimeter

Recruitment of junior staff
Staff amenities, housing
Maintain files, offices, workshop
Manage scheme transport
Operates intakes, pumps, canals
Offer mechanized services
Supervise water distribution
Deal with users' complaints
Resolve water user conflicts
Maintain plot registers
Liaise with political authorities
Deal with staff, tenant unions
Maintain domestic water supplies
Undertake scheme expansion
Crop financing, cash advances
Calendar of main operations
Arrange credit for farmers
Build and maintain field structures
Pay and supervise staff
Monitor on-scheme health status
Monitor and control diseases and pests
Cost recovery from water users
Crop research if necessary

Farmers/field unit

Acquire plot and water rights
Recruit and pay labor force
Field leveling
Supervise water application
Monitor water supply
Field channel maintenance
Husbandry skills for crops
Choice of crops and seed
Timing of field operations
Integration with other enterprises
Harvest and transport of crop

Table 50 continued:

User discipline/fines	Public health precautions
Resolve disputes over water	Utilize extension advice
Agree who is in charge	Maintain housing and structures
Pump operator and water guards	Protect and maintain field drains
Finance any joint construction	Insure necessary on-farm energy
Collect any user fees	Insure feeding of laborers
	Pay charges and debts

cross-cutting and overlaid functions within a large corporation. At one extreme where units are completely decoupled from each other, markets serve to provide "matrix management" through the blind interplay of supply and demand as each unit bargains in its own behalf and real goods and services move through the system. At the other extreme one has an encompassing hierarchy which determines coordination (and hence activity sequencing or movement) by planning. The fact remains that neither extreme works particularly well for intermediate cases, where the system is not so large that markets become desirable but too complex for efficient central control. A great deal of the recent management literature deals with the continuing search for better ways to achieve effective matrix management.

The attractiveness of "irrigation management" as a concept arises because the physical handling and transformation of water as it moves through various control structures and field operations provides a thread for lining many of the constituent components. A basic theme throughout this chapter is that this linkage is at the same time useful and seductive. It is useful in that the progressive narrowing of scope as one moves from main systems to perimeter control and then water use in farmers' fields corresponds to successive stages in real world activity. Water as a physical entity does impose a considerable degree of coordination upon a system, whether planned or not. Looking at how water is handled by different actors step by step--supply, conveyance, distribution and drainage--is bound to be a powerful and illuminating conceptual tool. Nevertheless, irrigation can also be viewed as a novel technology being promoted among farmers who have their own activities and needs and who may enjoy alternative sources of water. There remain many additional points for potential managerial intervention which are not closely tied to the hydrologic subsystem, though they may powerfully influence irrigation performance. Thus in addition to "matrix management" one requires concepts like "loosely coupled systems" and "the project cycle" to adequately describe the organizational environment within which irrigation occurs. Such items will be introduced in relation to the level where they seem most appropriate, but may apply to other levels as well.

The foregoing observations are neither an endorsement for having multiple agencies in charge of irrigation, nor do they imply that efficient "matrix management" is even operationally feasible. When viewed from a country perspective, nonetheless, a matrix situation clearly exists in African irrigation. Common patterns of inter-organizational linkages are portrayed in Table 51. These suggest that some African countries have already created complex support structures with numerous salaried staff at several levels. Getting these various sub-units to cooperate in a timely and cost-effective fashion can be extraordinarily difficult. As we shall see, the 1970s penchant for adding specialists at intermediary levels to do "matrix management" was counterproductive because it increased vested interests within the matrix without augmenting farm level output. The "structural adjustment" being forced upon African governments by donors has been accepted in part because poor countries simply cannot afford such a "modern" superstructure.

Sector Management

At the national level where decisions are required about the entire agricultural sector, responsibility over irrigation is usually split between several government departments, typically involving at least three ministries: Agriculture, Finance, and Planning (if there is a separate Ministry of Planning). In Francophone countries, because of the different role accorded to ministries of agriculture (which serve a technical function during plan formulation and may not have major operational responsibilities in their own right), the equivalent organization may be a semi-autonomous parastatal. It is not easy to obtain coordinated decisions from rival ministries, and there are comparatively few countries which can be said to evidence a well-formulated approach to irrigation at the national level.

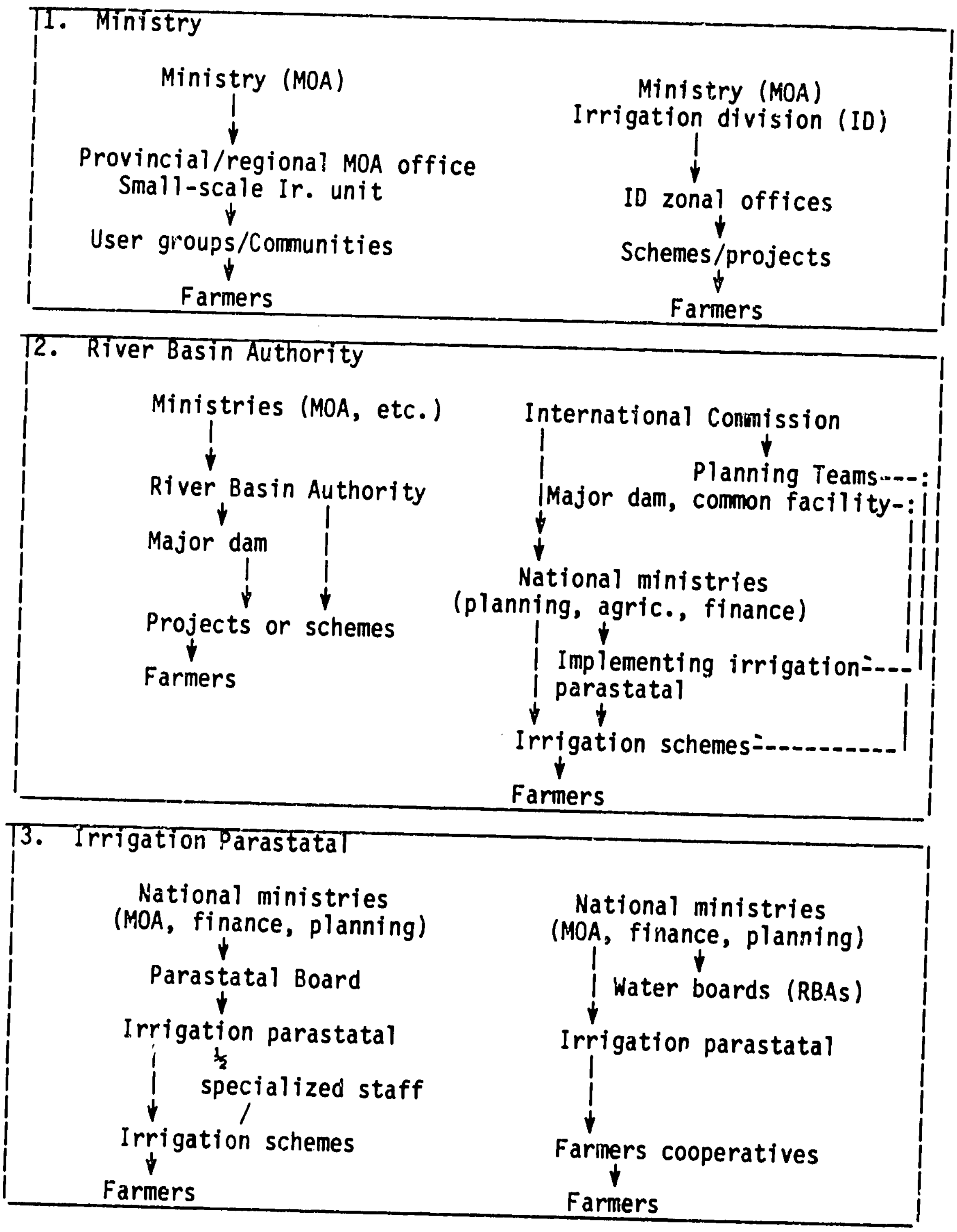
Countries with a very large irrigation sector, such as Egypt and Sudan, have separate Ministries of Irrigation solely concerned with insuring adequate water supplies for irrigation development. In both countries, irrigation engineering is recognized professionally (though retaining a bias towards a civil engineer's concern with water supply rather than irrigation agronomy, which comes under separate agencies). There are hundreds of engineers already in post, and a large pipeline comprised of numerous training institutions (particularly in Egypt, with by far the largest agricultural training establishment in Africa) to insure an adequate supply of manpower in the future. Somalia, anticipating the future importance of irrigation and power along the Juba River, has a Ministry of Juba Valley Development.

The more typical pattern is for irrigation to be the responsibility of a division or department within the Ministry of Agriculture (as, for example, in Tanzania). Sometimes following the FAO pattern this division will combine land and water, as within Somalia's Ministry of Agriculture, or it may include farm planning or soil conservation (as in Malawi and Zimbabwe at various times in the past). While the details of ministerial structure obviously will vary from country to country, the general features of a ministry as a civil service organization are broadly the same across Africa.

First, the sphere of ministerial action is generally defined by function. A Ministry of Agriculture is expected to give advice and support to crop producers, just as a Ministry of Water Development is

TABLE 51

PATTERNS OF INTER-ORGANIZATIONAL LINKAGES



expected to plan and construct new water supplies. The main complication in regard to irrigation is that it can be located in either ministry, and sometimes (as in Nigeria and Tanzania) gets shunted back and forth between them.

Second, in most African countries there is a tradition which separates technical experts from general administrators. Good technical people tend to become sidelined in the ministry structure, watching the advancement of their generalist colleagues with envy. Unwieldy formal sanctions and a desire to curb tribalism result in a high rate of transfers within job assignments. There is also a marked internal cleavage between the higher and lower level cadres within most Ministries of Agriculture. The lower staff, who are in most direct contact for farmers, suffers from weak training, poor morale, and a lack of mobility into the national system (Moris, 1987). Here irrigation engineers occupy a rather special situation, since to hold such responsibilities requires a high degree of training and there is less of a tendency to create a large cadre of subsidiary staff. Good engineers in Africa are very scarce indeed (except in Sudan), and they generally work with only a few subsidiary staff (surveyors, cartographers, and the like).

Third, ministry staff find themselves bound by civil service regulations. Staff recruitment and promotions are based on formal qualifications, sometimes little related to on-the-job capabilities. Financial controls are complex, and disbursement frequently delayed; usually all funds must be returned to the treasury at the end of each financial year. Development, recurrent, and manpower budgets may be separate and unrelated. The submission and approval of the budget is the big event in each year. Communication with outside agencies except on the most trivial matters is in theory to be channelled to the top first, to insure it accords with official agency priorities. It is, in short, a system more suited to the planning and management of its internal bureaucratic resources than it is to taking action at the various field sites where irrigation projects might be located. The weight of precedent and official procedures is so heavy that most operational irrigation agencies eventually break free to become self-accounting "parastatals" (see below).

Despite the disabilities just outlined, some African countries have left the operational control of individual irrigation projects within the Ministry of Agriculture, making it simultaneously a supervisory and executing agency. For example, in Tanzania as in Kenya, small-scale irrigation has been put under a section of the Ministry rather than being operated by river basin authorities (found in both countries) or Kenya's NIB. In countries like Malawi where irrigation is not a major concern this seems to be the general solution for managing all schemes not privately owned. Quite commonly such projects draw upon either FAO or bilateral donor support for technical assistance in the Ministry headquarters and on individual schemes. (The Taiwanese, Chinese, Koreans, and Dutch have been active in this regard; on-scheme staff are often provided by volunteer organizations.) We doubt that mainline government agencies are ever very adept at managing actual field operations (See Moris, 1981:56-57), but if they must assume this role certain minimum improvements should be considered:

- Installation of radiocall between the field sites and their supervisory office;
- Use of microcomputers to facilitate project monitoring and budget preparation;
- Establishment of autonomous accounts for each scheme, with annual balances remaining within each scheme for its use;
- Creation of mobile engineering support perhaps located at the provincial level to serve all schemes in a zone;
- Tight controls to discourage employment of salaried staff charged against individual schemes;
- Organization of inservice training for local leaders and any project staff working within schemes; and
- Exchanges of manuals and experience between countries. Here FAO and the PVOs could play a larger role than they do now.

Even where ministries do not operate irrigation schemes, their staff still exercise significant influence over sectoral performance by other means:

1) Policy decisions about pricing, priorities and equity;

2) Negotiations with external donors;

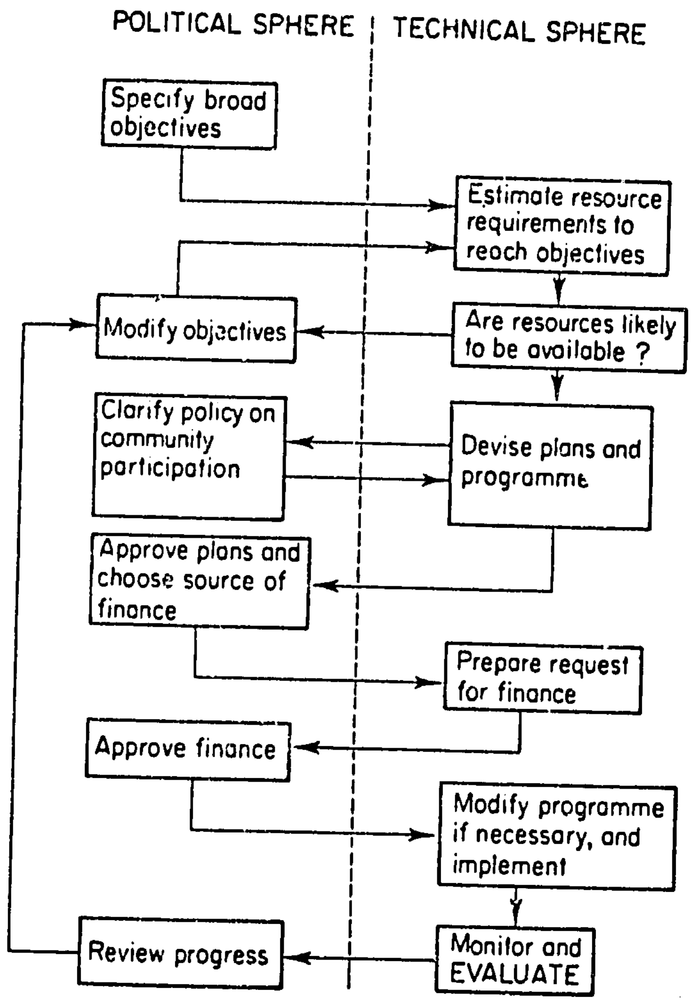
3) Attention to crop priorities and technology choice;

4) Manpower issues;

5) Choice of implementing institutions; and

6) Coordinating mechanisms.

Other chapters deal at length with the substance of <u>policy decisions</u> affecting irrigation. The managerial issue is rather how countries can insure that policy decisions will be raised and dealt with sensibly. Here there is cause for genuine concern. When countries have temporary access to windfall profits, as Nigeria did in the late 1970s, the privileged status of irrigation may encourage unwise investment; when they are bankrupt, they are swayed to accept whatever large projects the donors may offer (cf. the OMVS case). To avoid such mistakes requires that countries develop policy review as an on-going executive function. At present, the occasion for such attention occurs in the annual budget submission, and in the formulation of multi-year national development plans. Montgomery's review of senior SADCC managers found they were preoccupied with internal matters rather than achieving development goals (1987:917). Often policy formulation is thought to be the task of the political leadership. The point of leverage may be the ministry of finance, whose concern with investment returns might provide the basis for systematic review of irrigation policies. Alternatively, a planning division within the MOA might be assisted to undertake irrigation sub-sector planning.[1] Furthermore, policy formulation is not a single task which can be done optimally once and then "handed over" to others for implementation. Cairncross et al. show that effective policy formulation requires a sequence of interactions between the technical and political spheres (1980:142):



The involvement with external donors occurs because of the prominence of loan financing within irrigation, and to secure technical assistance required in project planning and implementation. The mechanics of this involvement can constitute a major drain on a ministry's scarce high level manpower. Haddon notes that in Kenya while in 1980 the Ministry of Water Development had hardly begun work on 64 schemes scheduled for completion in 1982, its senior engineers found themselves increasingly diverted to deal with donors (1980). These days the typical African country faces a continuous stream of donor delegations. Active in assisting irrigation have been the French, Dutch, British, Americans (in the Sahel), Italians, Japanese, Taiwanese, and Chinese, as well as the World Bank, FAO, the African Development Bank, IFAD, FAC, FED, and the EEC (and Arab financing for projects in Sudan and Somalia). Each project will require a sequence of visits and evaluations, and each donor expects its particular procedures and conditions precedent to be met. Just the drafting of enabling legislation can become a major staff preoccupation in the hard pressed ministry offices.

How to provide manpower planning is another unresolved issue in most countries, where this function was usually left to the Ministry of Education. Its importance arises because most countries are not geared to provide pre-service and inservice irrigation training, and lack their own high level staff in irrigation-related professions. There is a relatively long lead time in establishing such cadres from scratch, but unless this task is undertaken African countries will remain dependent upon external consultants for most project design. The only detailed irrigation manpower study for Africa which we have encountered is the Wright et al. (1982) analysis of Nigerian needs. A summary of this useful study is contained in the FAC Consultation on Irrigation in Africa (1987:91-110).[1]

The other major area of Ministry influence is in regard to the choice of institutional models for field projects. While a ministry can see that projects are planned and funded, usually it will be forced to establish subsidiary management units to carry the subsequent operational responsibility. The main options are described in the rest of this chapter.

River Basin Management

The coordination and planning activities related to water management over large areas can be assigned by function, by drainage, or by enterprise. If by function, one gets either a ministry of irrigation or an irrigation division within the MOA (as described above). If by enterprise, one will have an irrigation parastatal linked to a major dam or several large schemes (like Mali's Office du Niger). But it is equally feasible to identify the drainage itself as a basis for creating a support and coordination unit, commonly termed a "river basin authority" (RBA). Such authorities come in two varieties. Those attached to a very large drainage covering several countries are necessarily international in character and will have internal representatives from each country as well as separate country-level

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[1]Haissman (1970) might be of assistance, though based on Mexican research. His results are summarized in an article, "Generating Skilled Manpower for Irrigation Projects in Developing Countries," Water Resources Research, vol. 7, pp. 1-1.

implementing units. Here the OMVS serving Mauritania, Senegal and Mali in the development of the Senegal River is perhaps the best known example. There are however several others in Africa: the Nile Waters Commission (involving Sudan and Egypt), the Gambia River Development Organization (The Gambia and Senegal), the Lake Chad Basin Commission, the River Niger Commission, and the Kagera River Commission. Alternatively, where a drainage is mostly within one country, the leadership may establish internal river basin authorities such as those found in Nigeria, Somalia, Ghana, Kenya, and Tanzania. Such organizations have a number of features in common with irrigation parastatals (discussed separately). The choice between these institutional options probably depends on the degree to which they hold operational responsibility. River basin management activities can be thought of in relation to the project cycle, yielding in succession five degrees of increasing managerial involvement:

1) Overall coordination and policy;

2) Planning and data acquisition;

3) Project preparation and design;

4) Supervision and construction of facilities; and

5) Operation of systemic components.

While an international river basin authority might suit the first two activities, a country is more likely to opt for an irrigation parastatal when actual operation of perimeters is envisioned.

These issues which arise in "managing" irrigation on an entire river system (or drainage) tend to be distinct from the operational concerns which predominate at a command level. Depending on size, a river system may incorporate one or more provinces in a country; a major portion of the whole nation; or even the territory of several contiguous states. The vastly increased territorial scope usually entails an equivalent widening of functional coverage: at this scale, the topic becomes "water management" reflecting multi-use considerations rather than "irrigation management" in the narrow sense. Nevertheless, drainage wide and systemic wide considerations are still very important to the success of irrigation management. In hot and dry tropical lands, any larger project must depend upon either distant water sources or a very large catchment. A central component in the management of a river basin is obviously river management, the hydraulic control of flows through the system. But it can also entail several other functions: acquisition of hydrometeorological data, project planning, cost apportionment and recovery, allocation between uses, regulatory aspects, construction of facilities and works, operation of power supplies and irrigation systems, maintaining navigational aids, and the monitoring and control of impacts. The general problems associated with these aspects of river basin management are well covered in UN sources (1975, 1983) and in several overview volumes (Goldsmith and Hildyard, 1984; Godana, 1985; Lundquist et al., 1985; Hydraulics Research, 1986; Saha and Barrow, 1981). Here we shall merely highlight three aspects which are likely to be problematic in African settings.

Legal Issues

Legal issues should be expected to emerge increasingly within Africa's plans for irrigation and power development. At other points in this report (see chapter 3), there are many examples of water development projects which depend upon access to water which does not originate within the country concerned. Sudan's heavy use of water from the Ethiopian Blue Nile is one such case, but there are other apt instances: Somalia's reliance on Shebelle water and its plans for irrigation on the Juba; Cameroun's development with World Bank funding of its Semry I and II irrigation projects with water from the Logone River, which constitutes its border with Chad from where the Logone originates; Mali's diversion of Niger River water at Markalla into the inefficient Office du Niger at the expense of downstream users in Niger; and the Gambia's plans for developing the Gambia River originating from Senegal. The potential for conflict is especially acute where major developments are built by one country where only a short segment of the affected drainage falls within its own borders. For example, Cameroon's development of irrigated sugarcane along the Benue River comes only a few miles from the Nigerian border, and Nigeria has its own ambitious irrigation plans (Drijver and Marchand, 1985). If we take the large Cabora Bassa dam in Mozambique, only 11 percent of the basin occurs within Mozambique itself (Bolton 1986:157). On a continent where so many rivers are shared between states, legal arrangements which facilitate orderly and sensible development are vitally important.

Godana (1985) argues that doctrines of water apportionment based either upon first use or upon absolute sovereignty are inappropriate in such contexts, and are inadequate as the basis for international law.[1] In 1978 the Ethiopian Ministry of Foreign Affairs insisted Ethiopia reserved to itself all rights to exploit its natural resources--the issue in point being Egyptian and Sudanese worries about Ethiopia's plans for harnessing the Blue Nile's waters (Godana 1985:32-36). However, the reality is that Egypt and Sudan depend heavily upon water which comes from Ethiopia, and any major disruption would cause an immediate international crisis irrespective of the claims of individual states. Godana observes that in practice co-basin states must cooperate, but there remains a knotty issue of whether riparian rights (guaranteeing downstream users their water "undiminished in quantity or unimpaired in quality") or prior appropriation should govern access to international water resources. These two doctrines originated in rather different situations: riparian rights from English common law in a water surplus

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[1]The notion that states exercise absolute territorial sovereignty is sometimes termed the "Harmon doctrine" after U.S. Attorney-General Judson Harmon, who first authoritatively delineated it in 1895 when declaring U.S. power over the waters of the Rio Grande (Godana, 1985:33). For obvious reasons, the doctrine is more appealing to states which control the sources of supply on a shared drainage.

setting, and prior appropriation from the US West with its acute water scarcities. Neither approach is sufficient as a general guide to the resolution of water use conflicts arising from shared drainages.

Adams notes "the basic principle of river basin planning is to bring administrative boundaries into line with natural ones" (1985:178). This apparently attractive dictum is extraordinarily difficult to achieve in practice except where by lucky accident a discrete component of a drainage falls into a single province or political region. Funding within African regimes is generally channeled through either the politico-administrative structure in the national budget, or through zonal parastatals (in Francophone countries). River basin authorities which are not coterminus with either type of entity complicate further an already crowded organizational landscape. Here the ease with which national governments will pass enabling legislation establishing new authorities can be misleading. As Nigeria's Bakalori case (implemented under the Sokoto-Rima River Basin Development Authority) illustrates, the imposition of legal controls which ignore existing claims upon land and water becomes these days further cause for conflict. Technical efficiency is no longer enough to insure that the sometimes extravagant claims being advanced by Africa's newly formed river basin authorities will be seen to be both legally binding <u>and</u> legitimate.

The Hydrometeorological Network

The hydrometeorological network poses problems where a basin overlaps several countries or where major parts of it lack established records. It is quite common in Africa for there to be large gaps in the recording network, as for example, on upstream tributaries contributing to the Juba River in Somalia or virtually the whole of southern Tanzania (until Tanzania received Nordic assistance in the mid 1970s). Such gaps and the oft-times shallow time depth of records at individual stations contribute to the possibility that the probability of extreme events will be underestimated. Examples would be the unanticipated rise in the level of Lake Victoria in the early 1960s, reaching the highest levels since the beginning of the century (Abu Hoda in UN 1983:398), or the extraordinarily high Zambezi River flows which the Cagora Bassa dam had to withstand in March 1978--roughly five times the mean annual flood. With such high variability in potential flows, water control structures in Africa are usually conservatively designed to provide a substantial margin of safety above the anticipated mean flows, though of course this further contributes to high investment costs.

The managerial question is whether a river basin organization should itself take on responsibility for the routine acquisition of hydrometeorological data. The main reasons for doing so appear to be ease of access to donors, and the need for extra hydrological data when planning large dams whose catchment may lie in another country.

Dam Operation and Management

The establishment of a river basin authority along TVA lines is almost always linked sooner or later to the building of one or more large dams. This linkage is so obvious and direct that one can almost regard RBAs as "dam management" entities in the same way as irrigation parastatals are "scheme management" bodies. A large dam segments its drainage into two separate pieces, interconnected by the water release regime adopted by the dam's operators. For irrigation uses of this water, the main questions concern the timing and volume of water released. RBAs become associated with irrigation management because often the increased productivity from irrigation is used as a major justification for having the dam in the first instance. Sometimes, of course, as with the Bakalori Project in Nigeria, the dam itself is built primarily to serve irrigation purposes. However, in other instances designers aim to realize major hydropower benefits from the same structure. This can prove quite difficult in practice, since the extreme seasonality of flows on many African rivers leaves insufficient water for hydropower generation except at expense of stored water required by irrigation (see again the Bakalori case).

Scudder (1980) stresses the failure in Africa's earlier RBA projects to recognize the major adverse effects which loss of the annual flood imposes upon the thousands of small farmers who depend upon recessional irrigation for growing their crops (see also Drijver and Marchand, 1985). Along the Senegal, Niger, and Juba Rivers, as in Tanzania's Rufiji delta, the losses from planned dams will be considerable. Riverine forests, which constitute a strategic forage reserve in much of Africa, are likely to be similarly effected (a special concern in Kenya's Kerio Valley RBA). A partial and as yet untried "solution" adopted in the building of Mali's Manantali dam (an OMVS project) has been to plan for an "artificial flood" through large volume water releases, timed to coincide with the former annual flood. This requires a different design of the dam itself, and will not prevent the buildup of silt in the dam's "dead storage" zone within the reservoir.

While irrigation managers are generally concerned with the downstream water releases from a dam, in Africa the upstream management has also raised troubling problems. Mary Tiffen's chapter in this volume examines the plight of Africa's evictees, the people dispossessed from their farmlands by the flooding of a reservoir. The seasonality of water flow makes having large reservoirs highly desirable. But in a semi-arid landscape, the very lands suited to a reservoir will usually consist of the highest potential farmlands for miles around (and the key dry season forage reserves for livestock production). River basin authorities planning to build major dams need to devote much more attention to the compensation and relocation of existing communities. It is not ethical to pretend that equivalent land can be easily found; almost by definition, uplands in a dry environment will be far less productive than the rich alluvial soils flooded by the reservoir.

A final feature which distinguishes African dam management from usual developed country practice is in regard to upslope land use (and hence reservoir sedimentation rates when land is misused). Very high rates of siltation into the reservoirs of new dams have been experienced in Sudan and on Kenya's Tana River (under its TARDA river basin authority). In the Sudanese case, the problem is partly self-caused, since the regimes gave out huge tracts of land to be cleared for high risk mechanized cultivation in the very areas subject to soil erosion and draining into the Blue Nile. However, as Kenya's problems on the Tana River show, even when the immediate upslope areas are not densely settled there can be huge increases in the rates of sedimentation after a drought. Thus dam managers in Africa possess little real authority over land use within the catchment. A buildup of population and livestock in areas above a reservoir occurs spontaneously once a dam and its associated infrastructure has been put in place. It is quite possible Africa's major dams will have only 30-40 years of useful life before the live storage zone in their reservoirs becomes filled with mud.[1]

Parastatal Management

From an early stage, many of Africa's larger irrigation projects have been run by agencies termed "parastatals": public corporations financed with government funds but given a commercial mandate and permitted to establish their own regulations separate from the government's civil service procedures. In Sudan, there is the Sudan Gezira Board (SGB), formed in 1950 as a public corporation taking over the assets and responsibilities of earlier commercial syndicates. Subsequent schemes in Sudan copied the Gezira model, the Rahad Corporation being established to operate the Rahad Scheme, the Agricultural Production Corporation to operate the Khashm el Girba Scheme, and so forth. In Mali, the French government created the Office du Niger in 1932, giving it responsibility for constructing and operating Francophone Africa's largest irrigation scheme (de Wilde, 1967:245). In Senegal, there have been a succession of parastatals responsible for developing irrigation on the delta: the Senegal River Development Commission (MAS) established in 1938, followed by OAD ("Organization Autonome du Delta") in the early 1960s, and in turn by SAED (Société d'amémanagement et d'exploitation des terres du Delta) from 1965 onwards. By 1980, SAED had close to 2,000 employees and claimed to be the second largest employer in Senegal's Fleuve region (Miller 1985:40). In Mauritania, the first generation schemes were financed and supervised by the Bureau for the Development of Agricultural Production (BDPA), followed in 1976 by SONADER (Société nationale pour le dévelopement rural), which by 1981 employed 325 people stationed in three operational bases (Miller, 1985:30). And so it goes for most countries in Africa where irrigation is important: ONAHA for Niger, the National Irrigation Board (NIB) for Kenya, SEMRY for Cameroon, etc.

That irrigation parastatals are widespread in Africa is, then, abundantly clear. They have constituted the preferred institutional mechanism when African governments have wanted to develop large-scale irrigation with public funds. However, despite their legal similarities, these agencies have differed substantially in regard to the functions they provide. The Sudanese parastatals (described in chapter three) do

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[1]A situation which makes quite inexplicable the OMVS plans to proceed in closing the Manantali dam while delaying installation of power generation to use the water released.

not provide water at all: that is the responsibility of the Ministry of Irrigation, which employs Sudan's water engineers. They instead manage the production of official crops, in recent years evolving a considerable degree of mechanization which is then charged against tenants' accounts. With the Office du Niger, the agency did its own construction of scheme expansion and was responsible for an array of water delivery, production, marketing, and welfare functions: becoming, in de Wilde's words "progressively more or less sovereign within the limits of its territory" (1967:248). The National Irrigation Board in Kenya has its own schemes which are managed by Board appointed staff but operated as autonomous units with the proviso that the Board transfers funds and staff between them as required. This makes the Board both a managerial and a supervisory agency.

Advantages - Despite the presence of large parastatals like the TVA or the Bonneville Power Administration in the USA, parastatal management is not a topic understood by most American advisors. For example, western donors have urged African governments either to privatize their major parastatals, or else to prune their staff drastically. In Senegal, budget cuts mandated in the early 1980s forced SAED to reduce its staff by nearly 50 percent, which it achieved mainly by reductions in the number of its field staff (Miller, 1985:40). While such drastic measures may temporarily improve the organization's cash flow, they neither improve its output nor address the underlying causes of administrative malfunctioning. To deal with parastatals more adequately, advisors need to understand the tensions which led to their creation initially.

There are several reasons why public enterprises and parastatals have proven such a popular mode of approach within African countries. A properly run irrigation parastatal can:

- account for public funds, advanced for the attainment of specific objectives (generally claimed beyond the private sector's capability);

- deal directly with donors in the preparation of new projects without necessitating enabling legislation for each project;

- administer the contracts and negotiations required to get schemes established;

- recruit managers and technical staff under terms more attractive than usual public sector employment;

- provide specialized services to individual schemes without each scheme having to add its own technical staff;

- administer field programs which cross-cut administrative boundaries and the usual allocation of ministry functions;

- arrange crop financing for its schemes as a group rather than each scheme being forced to find its own support; and

- provide inservice training and other forms of organizational support including career structures not bound to a single site.

These are significant advantages when a government must deal with thousands of smallholders who cannot afford large cadres of salaried staff on each scheme. Thus while the creation of an irrigation parastatal is a form of government subsidy to the irrigation sub-sector, it is potentially more cost-effective than duplicating a range of specialized functions on each scheme. Of course, in countries with well-organized private firms to supply these needs (such as in highland Kenya or upland Zimbabwe), a government-supported irrigation parastatal may be unnecessary.

Weaknesses - The dangers which confront agencies like SAED or NIB are not unique to their water-related functions. They can be predicted from the history of similar agricultural service agencies throughout Africa. Crop agencies such as the authorities in East Africa or cereal marketing boards in West Africa are notorious for having evidenced pronounced organizational weaknesses. Among the more prominent have been:

- overmanning;
- overinvestment in unnecessary physical plant facilities;
- declining product quality;
- uncontrolled increases in overhead;
- rapid deterioration of equipment;
- widespread corruption; and
- alienation of farmers.

Since control over irrigation water and access to plots offer many opportunities for corruption, there is no reason to expect that irrigation parastatals will be exempt from these tendencies. Indeed, we suggest the dangers are so apparent from the experience of other parastatals that Africa's irrigation agencies should put their highest priority upon maintaining taut, cost-effective operation. The faults we analyze here are also evidenced at the scheme level.

Overmanning - Mali's Office du Niger illustrates the tendency on official irrigation schemes to let agency and scheme employment get out of hand. At its peak when construction activities were still underway in 1955, the Office employed almost 7,000 administrative staff. By 1964, the Office still had 4,700 employees (de Wilde, 1967:249). The key issue is how to keep a balance between size of operations and staffing. For example, Nigeria's Ogun-Oshun River Basin Development Authority employed 72 senior staff (30 of whom were in its Engineering Department) in 1979, at a time when it managed about 140 hectares. The Hadejia-Jama RBDA was operating about 2,500 ha with 58 senior staff (Wright et al., 1982:42). The consultants who looked at Nigeria's manpower needs for irrigation noted that this represented a "high degree of overmanning" even though Nigeria has an overall shortage of staff for its ambitious irrigation plans.

Uncontrolled Overhead Costs - Possibly the most difficult aspect for African parastatals to keep under control is their overhead costs. The reasons why these may balloon so quickly are not widely understood. First, in many African countries public sector salary levels are set administratively and are broadly similar within a given occupational cadre. As a consequence, in seeking to attract capable senior staff an agency cannot compete on the basis of salary, but instead will try to offer superior fringe benefits: housing, an official vehicle, land for growing crops, subsidized or even free electricity, and so forth. Second, it is quite common for accountancy systems to be oriented towards prevention of wrong-doing rather than managerial monitoring of the significant cost centers. Many bureaucratic organizations do not compute internal transfer costs. This makes it difficult to allocate costs to the internal benefits enjoyed by staff, in circumstances where they have a strong interest in suppressing such information. Third, employment of externally recruited specialists may create expectations that local senior staff should enjoy similar privileges. Fourth, in a deteriorating national economy the agency must often organize its own subsidiary services, such as shops, clinics, schools, and vehicle repair. And, fifth, in economies where the public sector is the major employer of salaried staff, it becomes very hard to resist external pressures to add staff at all levels within the agency. All five tendencies exist in heightened from within Africa, and jointly explain the high units costs typically encountered.

Inadequate accounts - Poorly kept accounts are a perennial difficulty throughout much of Africa, and should not be blamed simply upon a lack of qualified accountants. In any system where the people generating primary documentation do not understand its purpose or are perhaps even illiterate, the record will contain numerous mistakes, gaps, and irregularities. These cause frequent delays in the submission of accounts for review higher in the organization. At the intermediate levels, maintaining accounts in good order takes a great deal of extra effort not reflected in public sector salaries. Field units find they continue to lose their better accountants to private sector employment (and sometimes departing staff take the agency's funds with them). On their part, higher-level managers have a stake in keeping the financial situation muddled, thereby allowing their own overdrafts to pass undetected.

Most record keeping in African parastatals was originally designed to document that "proper procedures" were followed, as a guard against unauthorized diversions and outright criminality. The procedures themselves, however, can become very cumbersome over time. High turnover rates among senior staff make it difficult to explain irregularities identified two or three years later. Sometimes the financial year does not coincide with the crop year used by agronomists or the hydrologic year by engineers, so that aggregate cost data do not apply to the same period as do output data. Often the cost centers from which totals are accumulated have been poorly or arbitrarily chosen. Much irrelevant information is faithfully preserved, but the management cannot judge with any precision its current cash flow situation vis-a-vis its main enterprise activities. And, as already noted, the lack of procedures for transfer cost pricing means that numerous ancillary services and benefits get carried over unscrutinized into the general overhead costs. Our point is simply that agencies which operate within such an environment will find themselves perpetually "short" of qualified accountants, but this is a symptom rather than cause of their difficulties.

Premature Professionalism - African parastatals during the 1970s showed a huge appetite for measures aimed at making them more "modern" and "efficient"; computerization of accounts, better equipment, short-course training, and the addition of specialized, middle-management staff. We might note that this ballooning of middle positions was also taking place within US business organizations, which in the 1970s discovered "matrix management." Public service agencies when given the opportunity proved equally prone to the addition of specialized, mid-level managerial staff-- process Young, et al. (1981) termed "premature professionalism." While Young's warning was directed at the staffing of Uganda's Department of Cooperatives, the process can affect any kind of service or supervisory agency. Young portrayed a situation where there is a regulatory and support agency overseeing field units which operate commercial activities. When the field units display poor performance--as do many African irrigation schemes--the tendency has been for policy makers to add specialized, supervisory staff in the linked support agency. Such individuals, who in Africa come to high level assignments directly from advanced degree training, believe they are making a major contribution to increasing efficiency. They seem necessary as the price a country must pay for organizational modernization (and this can be true irrespective of whether they are in public or private employment).

What Young found, however, was that when those put in charge lack previous operational experience at the "shop floor" level, many of their innovations will fail to address the real problems. Overall efficiency in the primary organizations (here with individual schemes) does not improve, but overhead costs rise steeply. Even then, the newly recruited professionals will continue to think they are performing a valuable service in forcing field units to become more "efficient" and "scientific." These dangers of premature professionalism are most acute in situations where (as in irrigation development) there is a wide gap between what is taught in the classroom and what professionals encounter on the job. Then the rigid and oft-times inappropriate application of supposedly universal "principles" will introduce further costs and delays in an already chaotic situation. Furthermore, such actions reinforce an internal social cleavage between managers who are highly trained but lack experience, and workers who possess abundant experience but little relevant training.

One illustration must suffice. There are now available in the USA, Israel, and Europe very detailed hydrologic models which can be applied to understand irrigation problems. When these are introduced into African settings by a returned trainee, however, it rapidly becomes clear the necessary data are lacking. Unfortunately, to acquire high quality data becomes very expensive of senior management time, not just in the first instance but as a continuing commitment (Moris, 1981:31-45). A "managerial tool" intended to assist management becomes instead yet another source of managerial overload. The basic point of course is not that having specialized staff and quantitative models is either "good" or "bad." These are rather phase-governed interventions, to be added at that time when a program has reached a size where they become cost-effective.

Policy/Implementation Reversals - Most African agricultural parastatals come under some type of board or supervisory committee on which will be represented the ministries of agriculture and finance (and sometimes planning). The way corporate controls are applied by such bodies can itself become an aggravating factor, failing to rectify managerial mistakes and increasing corporate losses (Packard, 1972). What seems to happen is that a board's supposed policy-formulation role gets pre-empted by the notion that certain initiatives (such as wheat growing or support for a particular project) are mandatory irrespective of economic considerations (Quick, 1980). As a "privileged" technology, irrigation frequently receives this treatment (Moris, 1987). This leaves board members with little to do except meddle in what are properly implementation details. A strong general manager will resist this tendency, either by cowing the board into silence or being eventually forced out. Much the same conflict over who decides what is repeated in the relationships between parastatal and its constituent schemes. The parastatal's general manager (sometimes termed it "Director General") will in turn meddle in the detailed field operations of schemes which come under the authority's purview. The tendency to confuse policy and implementation matters at all levels is accentuated by civil service notions of hierarchy, whereby senior officials are held responsible in theory for all activities within their departments.

Corruption - We have left consideration of corruption to last, because there is little published evidence to document its prevalence and nature in African irrigation. Even so, on field visits one hears allegations which suggest it is a growing problem. We note also that in some circumstances corruption can serve positive purposes by keeping a system in operation despite gross economic distortions. For example, on one project the management has a whole warehouse for paddy not entered in scheme accounts and which is given out (two bags per Landrover) to the constant stream of official visitors. Other forms of corruption noticed during this study include the illegal sale of water to non-scheme pump operators, the giving out of plots to the relatives of agency staff, falsification of land and water claims, numerous examples of shoddy construction by contractors, "political" recruitment of technical staff, illegal sale of scheme crops through private channels, and so forth. We note simply that irrigation parastatals are usually the bodies expected to insure that scheme-level operations are honest and above-board. The contradiction is, of course, that the profits to be realized from

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[1]The two main references on this topic in Africa are Ekpo (1979) and Gould and Amaro-Reyes (1983).

corruption are greatest at the construction stage which is often under authority and not scheme control. If the supervisory parastatal is known to be corrupt, it stand little chance of insisting upon honest at the scheme level.

Parastatal Reform

The reform measures usually recommended for African parastatals mostly do not address the real causes of parastatal malfunctioning. Draconian "solutions" such as privatization or mandatory staff cuts are unselective and counterproductive, except in instances of extreme overmanning where the irrigation parastatal does not provide its schemes with operational assistance. However, the intensive preparation required for major irrigation projects and their isolated field locations force new schemes to depend upon a parent agency of some kind located near the national capital where most supply and policy decisions are made.

The Senegal government has experimented with "performance contracts," wherein parastatals like SAED must guarantee certain levels of performance in return for receiving public support during a fixed period (Sada Wane in Club Sahel/CILSS, 1982). USAID/Mali tried to extend this attractive innovation to an agency's relations with its farmers, with the support unit incurring contractual obligations to match those farmers must assume. As our Action Blé-Diré case (chapter three) shows, Action Blé Diré found for complicated and unforeseen reasons it was unable to honor its contractual obligations. The implication would seem to be that for farmers and their support agencies alike, it is the high level of environmental uncertainty which makes adherence to contractual obligations so difficult.

Scheme Management

Among the various managerial levels reviewed in this chapter, scheme managers have the greatest direct control over the components involved in irrigation. Usually a scheme is coterminus with the area ("perimeter") commanded from a single source. While "main system" management may be important in determining water releases from a dam or in arranging flow into a supply canal, the detailed arrangements for conveying water and distributing it among farmers fall upon scheme managers. They are the ones who usually control the pumping regime, rotations, system maintenance, land preparation, input supply, marketing arrangements, and cost recovery from farmers. Scheme managers must be concerned with the adequacy and use of water within an irrigation system, but they also arrange for many of the other inputs (fertilizers, insecticides, seed, etc.) which farmers require under an intensified cropping regime. To do this, they employ their own staff who usually live in an enclave within the scheme itself. Sometimes scheme managers are also put in charge of farmers' residences, involving the scheme in matters of land title, farmer recruitment, village water supplies and shops, and other welfare issues. The four-way split of managerial attention between water delivery, scheme staff, crop production, and farmers' welfare is typical of most African irrigation schemes. It is, as we argue later, a missing element from the standpoint of the professional preparation scheme managers are likely to receive. None of the main professions from which scheme managers are recruited--either water engineering, agronomy, or agricultural economics--adequately cover the full range of tasks a scheme manager must carry out once a scheme becomes operational. Where, as sometimes happens, scheme managers take up residence before physical works are complete, they may also supervise construction--adding still another realm of necessary expertise to what is already a very demanding job.

Of course, the situations which may require intervention by scheme managers are usually not fully apparent during a brief site visit. What outsiders see during the few hours they typically spend on a scheme will be the neatly laid out compound with its offices, staff houses, and nearby workshop, and the main water control structures such as pumping stations and the supply canals. However, the orderly activities observed during such visits will not be effective unless an equilibrium is maintained between the system's internal and external components. It should be recognized that because agricultural activities occur in linear sequence, any event which disrupts the chain becomes a threat to the scheme's ultimate output. In Africa, potentially threatening events abound, providing numerous occasions throughout the season where unless timely and effective managerial interventions occur, a scheme's productivity may be drastically reduced. Often farmers are not equipped to act in response to such threats. It will fall upon the perimeter's salaried staff (usually its manager or deputy manager) to recognize that a problem exists, and then to see that appropriate remedial actions are taken.

Anticipating Predictable Crisis

Field experience within Africa can provide some indication of the types of crises which are likely to arise. That these are not rare occurrences can be seen from the case studies reviewed in chapter three. Likely events which a scheme manager should be prepared to face while implementing irrigation development in Africa include:[1]

- Expiration of letters of credit before import approval from the national bank is received;

- Inflation of costs under a loan-financed project without any provision for increased external financing;

- Refusal of suppliers to accept government purchase orders;

- Disappearance of supplies and parts after arrival in port;

[1]A listing derived from Tanzanian experience, but validated by comments from managers working elsewhere.

- Deterioration of inputs when left unprotected en route to the scheme;
- Nonavailability of fuel from local outlets at critical periods;
- Damage to heavy equipment while being unloaded;
- Power outages during times of peak operation;
- Beadworks and intakes damaged or destroyed by flooding;
- Structures threatened by undercutting of the river banks;
- Cavitation occurs because of insufficient compaction and poor sealing of lined canals;
- Erosion on the face of an earthfill dam may threaten the structure;
- Rapid siltation occurs in canals and the storage reservoir;
- Gabion wire is stolen leading to the collapse of protective structures;
- Construction cannot be handed over because imported items are missing and hence specifications cannot be met;
- A coup or ministry shake-up makes it unclear who is in charge;
- Imported parts turn out to be for the wrong models of equipment;
- Heavy rains delay field preparation until late in the season;
- Land prepared early goes to weeds because of unseasonal rains;
- An influx of livestock from off the scheme destroys the bunds;
- An outbreak of army worm destroys the main crop;
- Key equipment units are diverted to off-scheme uses;
- Cement disappears from local supply outlets;
- The accountant disappears with a month's staff wages;
- Accounts and records are locked up while police investigate charges of corruption;
- An unseasonal dry spell kills farmers' food crops;
- Quelea birds arrive before the crop is harvested;
- Farmers suffer from an outbreak of chloroquine resistant malaria;

- A cholera outbreak brings a prohibition on movement throughout the scheme area;

- Cooling equipment breaks down and seed stocks spoil;

- Seed stocks are found to contain weed seeds; and

- Squatters take over a section of the scheme.

From a distance, such pressures seem almost amusing because they are so different from the activities specified in the usual project implementation plan. Experienced field managers will recognize that similar difficulties are present in most developing countries. It becomes easy to view them as typical "implementation problems" to be dealt within an ad hoc basis in the field (Moris, 1981:24-25). This overlooks the fact that such difficulties tend to be jointly encountered in remote African settings where many irrigation projects have been located. Several observations then become pertinent in regard to their managerial implications.

First, the difficulties are cumulative and interactive in nature. While similar problems are seen in Asia and Latin America, what distinguishes African irrigation is the greater incidence of individual problems and hence the heightened uncertainty in regard to eventual output. Production is overlayered with many sources of possible breakdown; it becomes an achievement simply to get through the season without major disaster.

Second, many of the difficulties are within segments of the larger economic system over which an individual manager exercises little control. Whereas in developed countries a manager's main attention is directed inwards towards components under a fairly high degree of control, in Africa managers must devote more effort to scanning the environment for adverse changes which may threaten production commitments.

Third, the more a production process relies upon external inputs (fuel, parts, servicing, transport, etc.), the more vulnerable it will be under a situation of a high level of cumulative uncertainty. Here irrigated production compares poorly with the local alternatives, since irrigation is often strongly dependent on access to external inputs.

Fourth, the more mechanized types of production will be more vulnerable. Anticipated "economies of scale" become diseconomies of scale if mechanization leads to greater risks because of increased dependency.

Fifth, production under high levels of uncertainty favors a different style of management. Highly formalized planning based on seasonal budgets and a staple environment gives way to opportunistic, "crisis management" characterized by rapid deployment of resources to meet daily exigencies.

Sixth, increased formalism within certain parts of the system paradoxically may only heighten the difficulties managers face in attempting to achieve an overall balance of effort. Many of the managerial improvements taught in textbooks are unlikely to be cost-effective if implemented piece-meal within African systems. Since disciplinary-based knowledge and procedures do not deal with the pressures and situations managers are likely to encounter, it is important that we search for alternative formulations which do address these needs.

Seen in this light, the reasons why irrigation technologies yield low efficiencies when employed as isolated components in an African landscape become apparent. As usually designed, African irrigation projects have tended to be input dependent, mechanized, mono-cropped, specialized, and large-scale. Since irrigation in any case involves a tighter coordination of activities, the resulting system becomes extremely sensitive to the kinds of interruption common encountered in African rural environments.

This situation contributes to the strong polarization of African production systems into two extreme types. Either they remain small-scale, low-input, multi-crop systems like those characteristic of "traditional" peasant farming over much of the continent, or else they evolve into a highly commercialized "enclave" sufficiently large to organize its own services and input supply. Thus while there are some examples of efficient large-scale irrigation in Africa, one finds few intermediate sized units which have grown out of smaller ones.

Five Managerial Domains

As earlier noted, there are potentially five main domains for managerial attention at the scheme level: construction, staff, water, crops, and farmers. The key point is to recognize that the degree to which each of these domains becomes a "problem" depends upon the particular circumstances of each scheme and upon design decisions taken about its development--decisions often made at a distance without any detailed knowledge of likely complications. Since it is the same scheme management which must address all five domains, a major problem in one sphere will usually result in less managerial effort in others.

The construction domain in theory shouldn't be a matter for scheme-level managerial attention at all. Most irrigation projects are constructed by different units from those who take over managerial responsibility once a perimeter becomes operational. Where events unfold in the planned order, all scheme managers are asked to do is to certify that construction is now complete and the contractor can be paid. However, actual circumstances in rural Africa are such that contractors face the same constraints and difficulties which the scheme manager does (note here the operational problems on Kenya's Bura West scheme). Very often essential supplies cannot be obtained locally when needed, heavy rains may render the scheme roads and tracks impassable, imported equipment may be ordered late (because of import clearances) or be delayed in transit, etc. Again, because the process is a linear one, delays accumulate over time and most African schemes do not start on schedule. Then, being one or two seasons late, construction work is rushed and the quality of construction suffers. When scheme management takes over, it will discover that immediate maintenance problems surface throughout much of the scheme because of improper and shoddy construction. An even worse situation can occur where in order to "save" construction costs, the Ministry of Agriculture or the irrigation parastatal decide that scheme staff will themselves carry out some or all of the construction activities. Then scheme managers will face the whole assemblage of field difficulties impinging upon the construction domain while also being held accountable for recruiting tenants, establishing crops, and supplying water. The main issues in this domain concern what to do about poor design while construction is in progress (since "variation orders" are expensive and can become a major source of further delay), how to rectify shoddy workmanship, the problem of missing items required for facility completion, and whether the scheme should do some construction work itself. Managerial control from the scheme is exercised through the parent agency's payment procedures to the contractor(s).

The second domain is concerned with scheme employees: both its salaried staff (who sometimes hold appointments within a parent agency) and its daily workforce of watchmen, water guards, pump operators, mechanics, drivers and the like. The skills required of management are at the same time technical and organizational: seeing that specialized tasks are done properly and on time, but doing so in a way which fosters teamwork and builds morale. These activities are usually lumped together as "personnel matters": recruiting staff, outlining job duties, clarifying reporting relationships, arranging for postings and promotions, supplying inservice and on-the-job training, and on occasion instituting disciplinary proceedings. However, there are complications which irrigation managers in Africa encounter that conventional personnel management fails to anticipate: the problem of tribalism, relationships with party bosses, accusations against workers made by farmers, the temptations of corruption, staff who go into business for themselves "on the side" while remaining on the payroll, and the problem of overly cumbersome or ineffective party officials' procedures for discipline and recruitment. It is also not necessarily true that scheme management controls all of a perimeter's staff. Under some systems, individual officials assigned to work within a perimeter continue to hold their appointments within other organizations and may not accept management's orders. A further difficulty is that many irrigation systems have been put in isolated environments where transport, schooling and medical services may be poor. To be assigned to work on an irrigation scheme may be seen by staff as "punishment postings" to be avoided if possible.

The third domain (assuming that physical works are complete and staff have arrived) is centered on the capability to deliver water to farmers' fields. Here the usual topics of interest to an irrigation engineer predominate. The main issues revolve around insuring an adequate water supply, protecting the infrastructure (power, fuel, spare parts, maintenance, and repairs), and providing mechanized activities. Those doing the tasks are usually employees, if not of the irrigation agency, then of the scheme itself. Their activities are subject to direct orders from management, and the equipment they use belongs to either the scheme or its parent agency. Thus within this domain, control-oriented managerial technologies are likely to predominate. The main uncertainties in Africa relate to the greater difficulty of insuring a reliable water supply, and the higher risks of breakdown associated with operation of mechanical equipment.

The fourth domain concerns the growing of field crops. The main issues are crop agronomy, crop protection, the competition between official and unrecognized crops, how to secure farmers' participation, and difficulties in scheduling and cost recovery. Those doing most of the work are the farmers, their family members, or hired laborers. Workers may be amenable to suggestions but resistant to orders. The property and equipment other than the land itself will belong to farmers and scheme members. The manager's control is usually indirect, and much bargaining may be necessary before managerial instructions are put into effect. The uncertainties arise from a host of potentially influential events and factors: disease outbreaks, the rainfall pattern, farmers' differential access to water, the timely and effective availability of inputs, and scheduling conflicts. Because of these uncertainties, an energetic scheme management may become tempted to take on a larger share of the responsibility itself, by operating its own transport system and perhaps mechanizing land preparation and crop spraying on farmers' behalf. This is what happened in Sudan's large irrigation schemes, and it resulted in the scheme management carrying a burden it was unable to fulfill so that both scheme and farm productivity suffered.

The fifth domain encompasses the larger organizational environment, centered on the matrix of supporting services as it impinges upon farmers' own social and economic organization. At issue are the scheme's relationship to local communities, the adequacy of technical support for seed quality, fertilizers, etc., and vertical reporting relationships upwards to donors, the ministry, and other government departments. In this domain, the scheme management owns nothing and controls very little. To be effective, it must become a supplicant trying to secure compliance by contracts, favors, legal controls, and persuasion. The actors are politicians, farmers' leaders, commercial suppliers, the district government, ministry supervisors, agency staff in other organizations, representatives of the treasury (or any other planning organization), external donors, and perhaps donor-financed contract teams. The uncertainties are many and varied, reflecting as they do perceived priorities in the larger system, the changing nature of political support, farmers' satisfaction and the means they may choose to voice disapproval, and the adequacy of other institutional services in the local environment.

Note that in the world visualized either by the technical specialist or by an agency bureaucrat, farmers enter only by virtue of their role in carrying out planned production tasks desired by the project. These viewpoints are strongly "top-down" in their basic premises, assuming that technicians and salaried specialists should determine what needs to be done, when and where throughout the system. Such premises are doubly reinforced in large irrigation systems, where the delivery of water clearly takes precedence over other activities. Many technically trained managers probably do not recognize a human element subject to separate priorities and constraints within their planning. They are accustomed to manipulating the hydrologic system directly. Control is limited only by cost and by engineering ingenuity. A computed water demand can be matched by an equivalent water release. Farmers become an encumbrance because they persist in mixing crops, varying their field operations, and in numerous other ways taking actions which appear to reduce irrigation efficiency. As three technical advisors on the development of the Senegal River put it (Hargreaves, et al., 1985:273-4):

> Block farming could be made mandatory. In the Sahel, with areas of large excesses of land and limited water supplies, low efficiencies and low yields should not be permitted. Availability of water may increase land values to ten or more times the value of dry land. Farmers accepting this benefit should also be compelled to accept a system that makes efficient operation and management possible.

Management in Loosely Coupled Systems

Smith, Lethem and Thoolen (1980) present an analytical distinction between projects oriented towards construction and those which promote generalized rural development. They draw attention to the greater degree of control which the management has in construction-oriented projects over the key components required for successful attainment of targets. Essentially, they argue, management's approach must be different towards things which are under direct control (where cost schedules and time budgeting are appropriate) towards things which while vital can only be influenced (requiring persuasion and bargaining), and towards "appreciated" but uncontrollable elements like rainfall (needing contingency planning, monitoring and information). This segregation of decision-elements into three categories corresponds roughly to the five domains outlined above (with domains 1-3 being lumped together). It helps clarify why specialists accustomed to an orderly and controlled system with its timetables and cost estimates may show inappropriate managerial responses when faced with significant but uncontrolled factors.

In domains characterized by "loosely coupled systems," control-oriented managerial technologies based on scheduling and command become counterproductive. Neither farmers nor service agencies are likely to respond positively if the approach to them is made by issuance of orders. The resources required are not scheme property; their commitment to irrigation must be realized through a skillful combination of persuasion, contracts, profits, and benefits. Political skills become more relevant than scheduling skills. Here those accustomed to exercising professional and administrative authority may find themselves defensive about approaching other interested parties, especially illiterate farmers, on an equal footing. Serious negotiation to discover farmers' constraints and priorities may be left until too late, when plans are nearly final and farmers' "approval" becomes a mere formality. Unfortunately, the strongly hierarchical bureaucratic culture fostered within field agencies reinforces this reluctance.

A rather similar dilemma arises when specialists in an irrigation agency try to arrange support from other administrative units not under the same ministry. The chains of command and intervening bureaucratic loyalties make it extremely difficult to arrange joint programs of work. Agreements will be reached, but by the time implementation begins one or the other of the parties will have been given different instructions from above. Because African bureaucracies are strongly hierarchical, to gain effective interorganizational cooperation will usually require either high level support (perhaps from the country's president or a powerful ministry) or else going outside the formal system to secure assistance informally (what Hyden has termed the "economy of affection"). Informal linkages and one's friendship network then become more valuable and reliable than formal plans--exactly the reverse from what civil engineers or economists will have learned in their professional training. As in approaching farmers, so also effective liaison with officials in other agencies depends upon persuasion, skill in bargaining, and one's political acumen. Perhaps this is true of all bureaucracies; it is particularly important within African administrative systems. This aspect receives major attention within a number of recent reviews of African management, including Hyden (1983), Heaver (1982) and Wiggins (1985).

Seen from the perspective of the individual scheme manager, the managerial tasks associated with irrigation development are likely to involve a spectrum of superordinate service agencies. Almost always one must deal with district and local government bodies, representing a country's general administration. Then there will be the legal system for establishing land and water rights, and resolving major disputes. Linkages are necessary to various service agencies offering credit, seeds, chemicals, inspection, quarantine, crop protection, insect control, crop storage, crop purchasing and marketing. There may be a Water Board which controls how water is allocated and used, just as there may be farmers' cooperatives involved in crop handling and marketing. Scheme managers may find themselves defending their capital and recurrent budgets before Ministries of Planning and Finance or even the legislature or party. Specialized agronomic and planning assistance may be required from external donors or from national level institutions. There may be also river basin authorities and other international bodies whose activities overlap those on an individual perimeter. In all these instances, a scheme's management finds itself in a comparatively weak position when soliciting support and assistance from above. We suggest that a service network with these characteristics fits rather neatly what the sociologist Aldrich terms a "loosely coupled system."[1] In terms of management theory, it is clearly a "matrix" situation.

Those dealing with irrigation projects from above have responded to

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[1]In loosely coupled systems, the constituent agencies tend to see each other as competitors. The information necessary for managing the overall system is often hoarded within individual units, and to achieve coordinated action requires a large communication effort done in a low-profile, non-threatening way.

the "loosely coupled" and "matrix" aspects of irrigation development in at least four ways. Some countries where there is a planning ministry or river basin authorities have tried to strengthen coordination through more comprehensive and detailed planning. A second response favored by donor agencies has been to coordinate activities within the project cycle, usually accompanied by establishment of a project management unit attached to a ministry or irrigation parastatal. A third response is to put individual schemes under the umbrella of a larger development corporation or board which can supply its own specialized services to constituent units. A fourth option is to centralize managerial control at the scheme level by giving the scheme manager a high degree of autonomy in developing and supervising scheme activities. If none of the first three options are pursued, scheme managers will tend to accumulate such influence automatically in response to the diverse tasks which require their intervention.

Hub-and-Wheel Task Delegation[1]

Those put in charge of a new irrigation project will usually find little established infrastructure already in place. Often their subordinate staff will lack specialized training and skills. Any tasks requiring such background will require the manager's personal attention. Nonetheless, a hard-working manager with a good grasp of detail can accomplish a great deal by dividing major activities into small components which can be assigned to a circle of subordinate staff. Usually there is not time to train each person to understand how the assigned task fits into the unit's total activity load. This leaves all planning and scheduling aspects to the manager. Provided subordinate staff do what they are told and the manager is attentive and hard working, the unit as a whole can be quite productive even in adverse environments lacking specialized administrative support. What typically occurs is that the manager assumes the central position in most activities, relying upon a "star" or "wheel" pattern for both communication and task delegation. Occupational psychologists note that such a pattern emerges quickly and spontaneously within unstructured work groups, and once evident tends to be quite stable. This tendency is reinforced in irrigation projects because of the technical mastery required at various points in production. Often, the manager may be the only person present who will understand why and how some specialized task must be done.

The short run success which energetic managers adopting this style of management achieve tends to obscure its negative performance traits. Psychologists have determined experimentally that those in the task group who do not hold the central positions receive little satisfaction and may become alienated. Since they each hold very specific assignments, if the manager should leave there will be nobody within the group prepared to step into the gap. Heaver (1982) points out that by allocating tasks rather than responsibilities, the manger absolves subordinates from any

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[1]This section draws upon the senior author's earlier work on African agricultural management, summarized in Moris (1981:118).

need to learn from their experience. The planning and organizing skills remain personal to the manager; if he or she is absent, the unit lacks the capacity for taking intelligent action.

The above faults were widely evident within colonial development projects throughout Africa, but it is a mistake to regard them as mainly a colonial phenomenon. The structural situation which can generate this kind of response is still widespread in rural Africa. It would seem that a "hub-and-wheel" approach emerges naturally in settings where a professional is expected to achieve dramatic results but is provided with only an unskilled workforce.

Managing by the Project Cycle

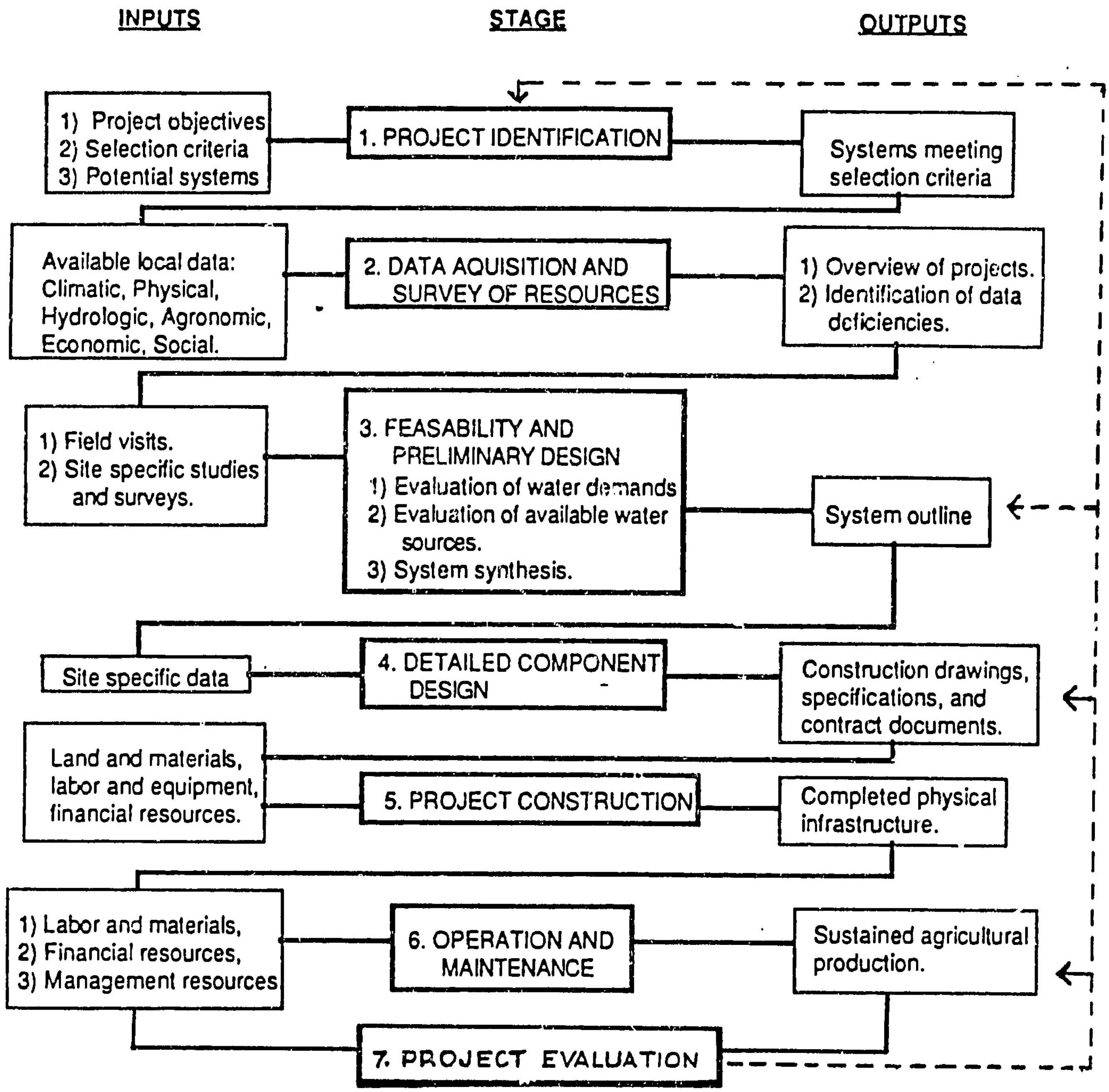
Another way to safeguard the integration of scheme activities is by linking them up within the project cycle, wherein each major component is allocated to an associated implementing unit. It is not immediately apparent that this is a managerial device; but in point of fact the project cycle as employed by donors basically has this purpose, since it does serve to minimize managerial intervention once a common program is agreed between all participants. A clear formulation of activities required over the life of a project greatly enhances the allocation of responsibilities between units and the monitoring of their subsequent performance. This is such an obvious advantage that these days almost all technical assistance projects are formulated within the project cycle framework.

As usually outlined for projects that have a major construction component (such as an irrigation perimeter), the project cycle can become quite elaborate at its initial stages (Figure 11 overleaf, derived from Wensley and Walter, 1985). Perhaps this reflects the fact that the professionals who design irrigation projects, typically either civil or irrigation engineers, do not subsequently manage them. Actually, irrigation management is not primarily a matter of applied irrigation engineering. Engineers in any field deal with the design and installation of systems. Inevitably, they focus upon physical structures, and hence upon investment decisions. While these decisions may either facilitate or hinde subsequent management, they <u>precede</u> the establishment of operational rules and the activation of an on-going production system. Those who must control water releases and schedule crop operations are generally in Africa <u>not</u> engineers; they come into the project cycle after the basic engineering decisions have been made. We stress this observation, because some of the texts on water management treat the topic as if it were mainly concerned with <u>investment</u> decisions (which is, of course, how engineers will tend to define their managerial concerns). The useful OECD publication, <u>Management of Water Projects</u> (1985) illustrates this point: it is <u>actually about decision-making</u> within the investment appraisal process, an important topic, but not equivalent to water management in the operational sense. Engineers do preliminary studies, identify sites, and design structures; but they rarely manage systems once these are established "on the ground."

The "loading" of specialized attention towards the initial, project planning strategies is reinforced by the application of economic

FIGURE 11

BASIC STAGES IN CONVENTIONAL PROJECT DEVELOPMENT



Source: Adapted from Wensley and Walter, 1983, p. 13.

appraisal techniques and by the fact those who insist upon having a project cycle approach are external donors, concerned that they are investing funds wisely. The many important decisions which must be taken within project implementation get collapsed into a foreshortened, single stage termed here "operation and maintenance" (stage six). It is left to the harried scheme manager to discover that this "stage" encompasses a huge and complex arena of further operations involving many components not even mentioned in the prior engineering and economic analysis. We reiterate that what is often termed "the project cycle" is in reality "the investment cycle." This feature of irrigation planning emerges more clearly if we contrast it to the situation in domestic water supply management, where the involvement of doctors and public health specialists forces engineers to pay more attention to implementation stages (cf. the excellent treatment given implementation issues in Cairncross, et al., Evaluation for Village Water Supply Planning).[1]

Ronald Ng of the World Bank has adapted the concept of a project cycle to yield operational criteria for monitoring irrigation project achievements. Ng sees the project cycle as depending upon successive "levels" (or stages) of activity, each overlaid upon the preceding one. His central idea is that different indicators are relevant for monitoring at each stage. At level A, when facilities are constructed, the main indicators relate to keeping on time and within cost estimates. The organizational technology for monitoring of construction activities is already highly developed and does not require further comment, except to note it bears little relationship to measurement of development benefits. Next comes level B, the operation and maintenance of the water distribution system. Here Ng's suggested proxy variable to measure success is the cropping intensity, which depends mainly on the reliability and adequacy of the water supply over the target command area. At level C, actual crop production becomes the focus of attention. Performance is generally measured by yields, either per hectare or per unit of water consumed (why not per unit of farmer's labor input?). A crude cropping index is no longer sufficient, since to obtain planned yields may also depend on availability of inputs, timeliness of agronomic practices, and realization of effective control over pests and diseases. At level D, the farmers' returns which motivate their contribution come to the fore. In the absence of full information, the simple calculation of net returns in contrast to available alternatives will usually suffice. And, finally, at level E in Ng's conceptualization one attempts to measure the attainment of broader socio-economic goals, not only at the farm household level but also within the community.

Ng stresses the need to change how a project is evaluated as it becomes established and operational in a particular environment. Often, only two types of performance have been customarily monitored when

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[1]Scudder (1985) presents a model of the settlement process based on four stages: 1) planning, infrastructure, and recruitment; 2) transition; 3) economic and social development; and 4) handing over and incorporation. Many irrigation projects never get beyond stage two.

irrigation is done by unspecialized organizations like a Ministry of Agriculture: 1) the engineer's attention to construction; and 2) the agronomist's to yields achieved per hectare. By themselves, of course, neither is necessarily linked to optimum scheme performance. Engineering timetables merely dictate the start-up date, indicating when the structures for water delivery should become operational. They contain no provision to measure the adequacy of design, nor do they insure that farmers will actually receive water in their fields. Crop yields are also misleading in some instances, since with most tropical crops there are curvilinear relationships and farmers may experience diminishing returns to scarce resources (their labor and capital, if not to water application itself).

There remains the question how to evaluate scheme performance on a case study or "cross sectional" basis. A useful framework from which evaluation can be derived at different states of scheme evolution is presented by van Steekelenburg and Zijilstra (1985), reproduced overleaf as Table 52. For those who prefer quantitative indices, there is the "Irrigation System Over-all Performance Index" (ISOP) proposed by Garces, Lazaro and Akhand (1986:166) based on a rating of 14 separate components. (One notes that 70 percent of this "overall" index is derived from various water measurements.) Such indices highlight the need to bring crucial socio-economic variables to the engineers' attention, a task Mary Tiffen attempts (1986) and covered also in earlier chapters.

Managerial Overload

An attribute of any high performance technological system is that the discretionary actions it requires fall within the competency of the managers who must operate the system. Managerial "load" can be thought of as the degree to which a given system requires discretionary actions in order to assure its smooth operation. More precisely, it depends upon both the number of discretionary actions and the effort required in making them occur--i.e., their "transaction costs." One notices that traditional systems for irrigation prefer simple and direct methods of operation. In contrast, introduced systems for large scale irrigation may require frequent managerial interventions at several levels. Sources of managerial tension which impinge upon scheme management include:

1. High levels of challenge and uncertainty in the natural environment;

2. Problems related to low levels of institutional reliability within the larger economy;

3. A differentiated, high cost and low performance structure for occupations in the labor market;

4. Difficulties originating because of import controls and national shortages of foreign exchange;

5. Widespread ethnicity and administrative corruption;

TABLE 52

GENERAL EVALUATION CRITERIA

I. Framework and objectives
- The operation's (project's, program's..) physical, socio-cultural, economic and development (sectoral, instrumental, thematic, "security", etc...) policy environment;
- Objectives as initially determined and as modified during implementation: reasons for choice? Still valid? Alternative concepts?
- Background details of the operation's design, preparation and execution.

II. Effectiveness (tangible results realized/intended results)
- Compare actual, tangible results (output and immediate objectives realized) with intended results (initial and modified);
- Analyze factors which have determined (a) the actual results and (b) the differences between these and the intended results.

III. Efficiency (comparison: value of tangible results/means employed)
- Assess value of tangible results, describe means, methods and time taken to achieve them, and analyze cost-benefit relationship thus obtained;
- Compare these figures with operation study forecasts and analyze reasons for any discrepancies.

IV. Viability ("after-aid"/sustainability)
Assess (or estimate) post-implementation survival of operation with reference to the following factors:
- Economic/financial: are recurrent costs of fully operational stage covered? foreign exchange requirements?
- Socio-cultural/technical/institutional: is the operation functioning properly, taking into account the motivation, skills and organization of those concerned?
- Policy: are development policies conducive to the operation's success?
- Socio-economic and ecological environment: is the operation "assimilable" and compatible with the conservation of renewable resources and protection of the environment?

V. Impact
Identify the operation's effects - foreseen or unforeseen, positive or negative - on development, i.e. in terms of irreversible improvement in the ability of the people and the institutions concerned to ever more effectively take control of their own future; who benefits, or not: women, youth, poor, better-off, government...?

VI. Conclusions and recommendations ("Janus" approach: 4 main points)
Formulate (a) conclusions and (b) recommendations concerning:
- The operational aspects of projects, programs, etc... evaluated;
- Development and cooperation policies relating to the sector or theme concerned and to the instruments of cooperation applied.

Source: van Steekelenburg and Zijlstra (1985), Annex 2.

6. Sponsorship of crops with relatively low payoff to farmers;

7. Stresses associated with attempts to institute double cycle cropping;

8. Difficulties arising from mechanization of scheme operations;

9. Problems of cost recovery;

10. Difficulties associated with settlement administration.

The first five are situational "givens": they would be encountered by any type of irrigation project. But it is significant that half the sources of managerial tension (items 6-10) arise from options chosen by system designers, and so could have been avoided. The fact many countries expect irrigation managers to promote crops which do not have a high farm level payoff is a tremendous disadvantage. Similarly, the unnecessary centralization under scheme control of production activities such as ploughing or transport saddles managers with continual worries over fuel availability, pilferage, and spare parts. So also with regard to the many time consuming tasks which arise if a scheme management demands farmers and tenants must live "on-scheme" in organized settlements.

One can also note what happens when engineers try to tighten control over water distribution without recognizing the interplay with other components in the farming system. Horst (1987:50) warns that trying to increase irrigation efficiencies by inserting additional control structures and increased measurement within a perimeter can actually increase errors and lower performance:

> The operations are often incomprehensible to the farmer, and many of the adjustments are hidden from view, thereby increasing the operator's opportunity of accepting bribes without discovery.

Engineers making design choices from a distance usually do not know how local staff will behave, nor do they understand farmers' constraints and preferences. Designs which optimize water use within a perimeter may require types of data and levels of managerial skill which the local system cannot supply.

Since these observations are detailed at length in other chapters, let us simply acknowledge that the "problems" of African irrigation management are in part self-caused. The managerial input emerges as a key constraint within African irrigation because the systems designed require a large and sophisticated managerial input in excess of what most countries can supply. Not only have many African irrigation schemes been very capital intensive--in the mistaken notion this would give greater reliability and would require less maintenance (van Steekelenburg and Zijilsra, 1985)--but they are also very management-intensive.

Community Managed Irrigation

"Management" at the water user association or community level refers to two, radically different types of management: integrative actions taken by farmers themselves, acting either individually or in concert; and actions taken on users' behalf (by technical staff, farmers' committees, NGOs, etc.). The "who manages what" issue ultimately comes down to the question whether farmers make decisions themselves (implying some mechanisms for coordination) or whether other people--salaried staff, community leaders, clan elders, etc.--can instead dictate what should be done. There is an underlying tension at the farm level between the fact that sensible use of shared water requires a fairly high degree of coordination, and the lack of anyone other than farmers with the resources to act. To operate efficiently the system may require money and effort devoted to the creation and maintenance of common facilities--headworks, pumps, distribution boxes, and canal lining--whose benefits will not be fully realized unless farmers coordinate their own independent farming activities.

There is thus a large element of "externality" intrinsic to the operation of smallholder irrigation based on a common water source. A farmer at the head of a tertiary canal who allows it to become choked with weeds in effect shuts off the systemic benefits from the others who share the same tertiary. Anybody who insists upon pumping a borehole dry without allowing time for recharge can cause a breakdown which destroys the supply for everyone in the vicinity. Failure of individuals to control insects, to observe an agreed rotation, or to make speedy repairs can jeopardize production for the group. The many interconnections, both temporal and spatial, within intensive irrigation make coordination essential: what some analysts term "water discipline." We have already pointed out that while this requirement also applies to large-scale farmers, because many of the coordinating actions occur at the field level the necessary adjustments will occur within the same operator's sphere of responsibility. While outside agencies may advise on water application routines, they can leave it to the operator to judge which trade-offs best suit local conditions. However, within a smallholder system these same trade-offs may pit one operator against another, and a formal structure for arriving at managerial decisions becomes necessary.

The minimum criterion for judging what is "good managerial performance" at the user level is simply whether or not the necessary types of coordination occur. Do users have a method for dividing scarce water between them at times when the flow is insufficient for overall demand? Who notices and mobilizes group action if a supply canal ruptures? Do farmers cooperate to raise funds for new capital works, such as improved intake structures? Who pays for fuel, parts and mechanics for operating pumps? Do people maintain parts of the supply system which are not on their own land? Questions of this nature will soon elucidate the kind of managerial system which farmers employ (see chapter three in regard to indigenous irrigation). There would seem to be at least five main options (other than a formal scheme):

1. Formal cooperatives, where users become registered members and

are subject to the normal regulations applied within a country to primary cooperative societies.

2. Water user associations, a special purpose grouping of farmers within the community for the specific purpose of managing a given supply, and usually incorporated under the provisions of national water laws.

3. Village projects, typically managed by a committee or council of elders within the community. Traditional furrow systems might be run by clan elders, whereas in the modern system the village headman, subchief, or village committee may hold responsibility for the system.

4. NGO projects, where an outside, nongovernmental organization (often a mission society) builds and operates a system, usually in liaison with a farmers' committee.

5. Private operators, where one or more individuals band together to buy a pump or to improve a supply and who control access to its water.

What these managerial forms have in common is that all are found within the immediate locality. Effective coordination of water users is simply not feasible from any great distance (as some missions have learned after giving farmers pumps while hoping to retain managerial control from far away). Managerial actions are strongly conditioned by local constraints: availability of mechanics, whether there is a bank, fuel storage, the honesty and effectiveness of local leadership, ethnicity, and the degree of social inequality. Studies of other forms of local cooperation (such as marketing cooperatives, resettlement, tractor hire services, and the like) suggest three findings which also apply in this sphere. First, to a considerable degree the problems of management at this level are shared across organizational types: cooperatives experience much the same problems as do village projects or water user associations. Second, it is extremely difficult to avoid capture of benefits by local elites, whose interests may lie in monopolizing outside assistance rather than seeing it is used for the common good. Third, those communities which are inegalitarian tend for obvious reasons to be much more difficult to organize (King, 1981). Forms of cooperation which have worked well elsewhere may become frustrated by local antagonisms and by the lack of any tradition of working together.

From this broader experience with local development associations in Africa, it is possible to highlight aspects of project management which are likely to cause the most difficulty:

- The holding of money in large amounts on behalf of the group;

- Any employment of salaried staff (difficulties in recruitment and payment;

- Protecting equipment from improper utilization;

- Keeping special resources (fuel, transport) for the assigned purpose;

- Protecting equipment from vandalism;

- Activities which regularly require a large labor input;

- Cost recovery from members at the times required;

- Keeping leaders accountable to members.

In remote African settings three domains of managerial action time and time again have proven problematic: 1) achieving corporate identification and accountability on a non-kinship basis; 2) managing money (and in particular enterprises requiring continuing cash outlays); and, 3) managing equipment shared between more than one operator (cf. the problems of Africa's tractor hire services). Unfortunately, irrigation projects require fairly high levels of proficiency in all three domains. One can predict consequently that management at the water user level will be a source of major and continuing problems.

Where there are many water users subject to severe but varying family and financial constraints, and having diverse crops and water needs, almost any common action can become controversial and hence difficult to arrange. We suggest that managerial actions at the water user level tend to have quite high transaction costs when they require coordinated action from many users. These high transaction costs may explain certain observed features of Africa's more successful small-scale irrigation systems (see chapter three):

- A preference for mechanical distribution routines which do not require discretionary actions from members;

- A preference for division of water in fixed proportions irrespective of its availability;

- A preference for arrangements where the immediate beneficiaries must initiate action and do most of the work required;

- An avoidance of regular salary payments which would require contributions from members on a regular basis; and,

- Reliance upon an influential and trusted local leader to manage funds and take technical decisions on members' behalf.

The desiderata for new systems would appear to be that they are perceived to be equitable, that they require a minimum of adjustments during the season, and that they minimize the cash demands put upon members. Systems which do require a fairly high discretionary input, such as in small-scale pumping, seem to be more popular when under individual control where the operator can take decisions director. (Further guidelines concerning the operation of small-scale irrigation systems are contained in the concluding section of Chapter Six.)

In the end, a source of continuing managerial input must be found if an irrigation project is to take local root. The worst case would be for physical works to be construed without anyone feeling responsible for them once they are handed over. This seems to have been the unintended outcome from many of Africa's drought relief projects, constructed with external grant funds. These days Africa's dry lands are dotted with derelict windmills and badly maintained dams, most of which were built in the expectation that by some mysterious and unspecified process a form of community management would emerge simply because a facility had been established on the ground. We suggest, to the contrary, that effective management requires the tangible exercise of either persuasion or authority: somebody interested enough in the outcome to organize farmers' activities to the extent that they coordinate their use of water and supply, necessary maintenance, and operating inputs. To obtain this input from a local system, at least a few people in it must regard themselves as being both responsible and capable. Whether the operational group is a cooperative, a water users' association, or a project committee is in the last analysis irrelevant: what is essential is that users of a system share a commitment to its success.

The many difficulties African village projects and various types of cooperatives have experienced in country after country over the past three decades would suggest that creating a local capacity for irrigation management is a daunting task. While there is a large and now somewhat dated literature on African cooperatives, this body of materials did not yield much analytical insight into <u>how</u> more effective forms of local management might be fostered. The work of Belloncle and others on local organization within Sahelian irrigation systems constitutes an obvious beginning, (Belloncle, 1982 and 1984, Diemer and Van der Laan, 1983), but should be supplemented by close attention to the well-documented Asian experience (FAO, 1982; Bagadion and Korten, 1985; Lynch, 1985' Oad, 1986; Coward, 1985; and Uphoff, 1986). The components dealt with are only partly technical in nature; what has been missing are focused analytic studies which examine the interface between how water is managed at the perimeter level and the evolution of more effective roles and procedures in the administrative and political sphere (Coward, 1985).

On-farm Irrigation Management

There is an enormous international literature which documents crop water needs and response under different water application regimes. Various FAO publications provide these results in readily accessible form, and are the usual source for managerial guidelines when new schemes are being put into operation.[1] The reason so much work of this nature is done is obvious: it can always be made to seem a high priority task to occupy scientists posted to work in Africa's under-resourced research

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[1]See the many valuable reports contained in FAO's irrigation and drainage series.

stations. Crop water measurements can be done at stations, and do not involve the many complications which on-farm trials present. We can therefore assume that work along these lines will be continued irrespective of its diminishing marginal returns. Less widely employed in Africa but also available are USDA and USBR publications based on the American experience, much of it derived from state experiment station research undertaken for the same reasons. Weaknesses to recognize when using synthesized results from either USDA or FAO concern: 1) a failure in the earlier work to look at interaction effects between variables; 2) the widespread employment of assumptions which invalidate the results under African field conditions; and, 3) the thinness of extreme case examples (more frequently encountered in Africa).

Because these technical reports seem readily applicable, it is easy to fall into the logical trap of assuming that further work along similar lines on a crop by crop, zone by zone, and country by country basis is desirable, and that such on-farm water consumption data constitute a sufficient basis for the framing of farm management recommendations. In reality, the managerial dimension is largely missing within the huge body of technical research on tropical agronomy. Management deals with uncertainties, with trade-offs between contradictory objectives, with existing competencies (both individual and systemic), and with experienced levels of risk. It is ultimately about the integration of farming techniques into a viable socio-technical farming system, not the optimization of returns to an individual technique.

Whereas Africa's field agronomists have learned this lesson, those compiling the manuals have not. Experimental research has in the past concerned itself mainly with optimizing crop yields under ideal conditions divorced from most of the managerial constraints one finds in field application (Belshaw and Hall, 1972). Research scientists experienced little difficulty in obtaining imported insecticides, herbicides, and fertilizer. They used wage labor on their plots in whatever amounts a treatment requires, and typically did not even measure the labor input required by particular operations. In effect, the procedures employed during Africa's first three or four decades of agronomic research assumed high standards of management, and treated land and water as the main limiting variables. Results which take into account interaction effect, labor inputs, levels of risk (natural and institutional), and the likely enterprise combinations which would meet farm family objectives were simply not compiled. Obviously, these are gross generalizations which do not apply to every study and which are untrue of the recent off-station "farming systems" research. But they are, we submit, a fair characterization of the kinds of results utilized by most Ministries of Agriculture when framing irrigation recommendations.

Instead, on-farm irrigation management is evidenced when farmers integrate irrigation technologies into their wider economic activities to realize objectives they consider important. In the perverse economic situations which confront many African smallholders, farms should diversify rather than specialize, should spread their planting dates and mix their crops, should minimize use of purchased inputs, and should adjust their choice of enterprises to reduce peak labor demands. Market imperfections also give them a high incentive to produce their own food and to minimize reliance upon external producer services. This prescription describes how many African peasants do farm; advisors who wish to promote a demand-led spread of irrigation technology must then devise technical packages which are efficient within these constraints. In essence, this implies less concern about optimization and more attention to sustainability. It is ironic that whereas natural scientists think adoption of irrigation will make African production more reliable, in its contemporary form the specialized, input-intensive and supply dependent character of modern irrigation increases farmers' vulnerability to exogenous forces.

Further complications outlined in chapter six relate to farmers' lack of integration between the various "farm" enterprises. With the exception of a minority of "progressive farmers," while rural Africans live in households, the heads of those households do not own and manage family farms (Moock, 1986). Crops are grown on plots, sometimes with separate plots for men vs. women, outsiders vs. relatives, and the young vs. their elders. The lack of integration between crop enterprises and animal production is one indication of the disconnected character of smallholder agriculture, but it is also evidenced by marked discontinuities within what seems to be the household "labor force." What external analysts will describe as "irrigated farming" are instead speculative investments made by individual members of households in expectation that these may provide some incremental food or income. Any analysis which assumes a tight integration of household resources and automatic sharing of returns is bound to yield misleading prescriptions.

African smallholders also reach their decisions over the course of each season in ways different from what farm management analysts assume. The many overlayered uncertainties which affect output unfold as a season progresses and cannot be predicted with any certainty in advance. A farmer would be foolish to commit a fixed package of resources (of seed, labor and fertilizer) to a single enterprise mix which is then kept in force over the whole season in the way that farm budgets assume. Instead, most annual crop cultivation can be termed "response farming": a sequential adjustment of effort and the enterprise mix decided as a given season unfolds and it becomes apparent whether a given season will be wet or dry, and which particular pests and disasters must be avoided.[1] The high variabilities seen in on-farm yields within Africa suggest there is much scope for better husbandry management, but the causes are likely to be quite different from those which western farm management addresses.

Which concerns, then, should receive attention in on-farm irrigation management? Chapter four provides several main candidates: suitable field leveling techniques, weed control, avoidance of salinization, and the choice and operation of small pumps. There are many further

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[1]The term "response farming" has been coined by Stewart (1986), but describes a strategy long utilized by Africa's dryland farmers.

unknowns: how to irrigate while intercropping; adapting irrigation to low-input farming; application methods which do not restrict crop choice; cost effective methods for supplemental irrigation to food crops; how to combine an irrigation cycle with rain-fed production of food crops; the integration of bananas, cassava, and a tree legume into field systems; whether returns are higher to irrigated woodlots or to treerows within the field system; when and where to pre-irrigate; nematode control under continuous irrigation; biological methods of pest control suited to irrigation; cost-effective options for irrigation on sandy soils; comparative returns from minimum water application regimes; and ways of utilizing drip and bubble irrigation with dirty water.

The larger goal should be to evolve research and extension linkages wherein farmers' perceived operational difficulties serve to orient the content of the applied research effort. The doubts already expressed about Africa's existing agronomic research arise because so much of it has been derived from researcher's preconceived (and usually discipline-grounded) problems. Similarly, it is a tremendous mistake to press poorly screened results upon farmers through an intensified, "top-down" extension methodology such as the World Bank's "training and visit" system (Moris, 1987). Perhaps, then, the absence of irrigation specialists within much of Africa could yet prove beneficial if, as a consequence, this type of professional assistance can be provided in new and more cost-effective ways which begin from awareness of farmers' own priority concerns.

Missing Elements

One cannot visit very many African irrigation projects without becoming aware of major gaps within the managerial systems as they are presently encountered. Nine missing or problematic elements have been identified in other chapters. While some will be discussed in our final chapter addressed to donors, it is helpful from a managerial perspective to include them in a consolidated listing here:

1) Weaknesses in staff recruitment;

2) Unprepared scheme managers;

3) Lack of feedback from operations into design;

4) Missing system architecture for small projects;

5) Systemic reasons for poor maintenance;

6) The cost recovery conundrum;

7) Ballooning overhead costs;

8) Absence of irrigation engineering; and

9) The lack of irrigation extension.

Staff Recruitment - A profound difference between most sub-Saharan African countries and nations like Sudan and Egypt (as well as developed countries) arises in regard to how staff for the irrigation sector can be recruited and trained. Countries with a large historical commitment to irrigation enjoy an enormous advantage when recruiting staff for new projects. The candidates who put themselves forward will usually come from a farming background or will have extended experience with relevant technologies. Such individuals do not require familiarization with irrigation equipment, and they understand the constraints and limitations associated with irrigated farming. This "hands on" experience allows formal training and recruitment to concentrate upon the supply of advanced skills needed for particular jobs. When people receive such skill training, they can readily put it to good use because of their previous background. Unfortunately, similar types of specialized training will not have the same beneficial effects when provided to staff who lack previous operational acquaintances with irrigation technologies.

In African countries which are trying to build up a local competency in irrigation management, the tendency has been to focus upon a rapid expansion in formal, pre-entry training. The danger is that this creates young and inexperienced technical cadres, whose professional staff cannot provide the operational insights which irrigation development requires (cf. the "premature professionalism" argument). Furthermore, highly trained young professionals are probably more prone to become part of the "brain drain" by accepting overseas employment.

It might be more effective to concentrate instead upon mature staff, by providing inservice training to deepen their understanding of irrigation technologies. Most African countries do have experienced project managers already acquainted with the agronomic problems of tropical crops. Such staff if given an up-to-date review of irrigation technologies could manage new irrigation projects without incurring the risks of "premature professionalism" (described earlier). In any event, we suggest that many African countries will find their shortages of skilled technical staff just as limiting as are capital constraints in regard to the scope for future irrigation development.

Preparing Scheme Managers - Schemes, as organized corporate entities in charge of the farmers who live within given perimeters, are nearly universal within African irrigation. While scheme management can be treated as if it were project management, the two spheres are not identical. There is much that a scheme manager does in Africa which will not be covered within the usual treatments of project management as a subject.

From the standpoint of agricultural professions (and applied science), scheme management is an invisible topic. Most scientists advising on agricultural development come from large farming traditions where the farm operator makes most production decisions without requiring assistance other than advice. They see irrigation management as being principally water management, either its conveyance and distributional aspects ("main systems" management), or its field application ("on-farm" water management). We saw earlier that these constitute but two out of the five domains where managerial interventions are required. Those preparing to become scheme managers need a balanced professional training which deals with all five domains in an integrated fashion. A partial training in specialized skills from any one domain will not suffice, no matter how relevant that particular specialty may prove when it is required for solving an emergent problem. The fact remains that managerial responsibilities cross-cut the entire spectrum of scheme components, and managers must be prepared to intervene in any domain which threatens the attainment of scheme objectives. Much closer attention needs to be given to documenting what scheme managers do while on the job, so that training and recruitment can be matched to actual managerial demands.

Feedback from Operations into Design - There is at present no device to insure that project designers have access to operational experience acquired by those who manage mature schemes. Dividing the project cycle into stages done by different specialties breaks the connection between design and its consequences. Scheme designers are usually civil engineers and economists. They are employed on a given design task for only a short period, and rarely return to see how the design fares once the scheme becomes operational. Most come from overseas offices to which they return on the completion of their assignment. The learning that occurs will take place in the consultants' home firm, not within the national agency on which behalf the design has been prepared. This explains, we think, why the same mistakes are repeated again and again despite being identified in many evaluation and project completion reports. The social and economic problems seen on Africa's current schemes have been an obvious feature for several decades. Their persistence is evidence that a sharp discontinuity between designers and implementers inhibits the accumulation of useful experience.

System Architecture for Small Projects - The discussion of small-scale irrigation (in chapter six) noted Wensley and Walters' (1985) observation that communal systems need a different "system architecture" from the format used in preparing large projects. In this chapter we broadened this category to incorporate all types of small systems, whether run by villages, cooperatives, water user associations, NGOs, or private individuals. What they share is their inability to support salaried staff or to repay the costs of elaborate project preparation. While a start towards providing technical help in a different form has been made by the creation of Ministry-based "small-scale irrigation units," less bureaucratic procedures are required for rendering such assistance. Technical staff at this level need to learn how to work with local farmers more effectively.

Systemic Reasons for Poor Maintenance

Both in chapters four and ten, the evident lack of maintenance within African irrigation projects is noted. When there are so many projects showing rapid physical deterioration one can conclude that underlying systemic reasons are responsible. Keeping a project's water distribution system maintained is clearly a management duty. If projects show signs of obvious neglect in case after case, there must be structural causes inherent in how African projects are designed and implemented. Chapter ten urges donors to give this topic high priority within applied irrigation research, which might profitably employ a "diagnostic" approach at both farm and scheme levels. From the analysis in chapter four, it would seem that poor maintenance at the scheme level can be attributed to weaknesses in managerial "software": a failure to appreciate and apply simple maintenance procedures which would yield great savings if routinely employed. We recommended that insofar as pump-based systems are concerned, African irrigation agencies might draw upon the experience with domestic water and sanitation (cf. AID financed WASH project reports by Camp, Dresser and McKee and similar Dutch and Scandinavian work). The World Bank has devoted considerable attention to improving maintenance within its rural roads projects (World Bank, 1981; Mason, 1982; and Cook, et. al., 1985), which would be directly relevant. Also of potential use might be the ILO's "guided transmission" training (Donarski, et al., 1983). The design of scheme level interventions should be preceded by careful analysis of farm-level constraints, which (as chapter six indicates) are probably more severe than scheme managers realize.

Cost Recovery Mechanisms

How to obtain scheme and project cost recovery from subsistence-oriented farmers remains perhaps the single most pertinent farm-level issue. The imposition of single channel marketing for an official crop, from which seasonal expenses and water charges can be deducted, has been almost the only solution African irrigation parastatals have found. As implemented in Senegal, Sudan, and Kenya (see chapter three) this "answer" has been accompanied by further complications:

- It may commit management to promoting unpopular crops, which give low returns to farmers' effort.

- Sometimes scheme policing of farmers' crop sales is required, making management the farmers' adversary.

- It puts pressure upon scheme managers to become responsible for all aspects of crop production, making farmers little more than sharecroppers.

- Deducting all production costs from a single crop will make it seem even less profitable than it is, further depressing farm output.

- Faced with declining output, scheme managers resort to the threat of expulsion to safeguard their control. This in turn means they become settlement managers as well as providers of irrigation.

The socio-economic consequences of this set of interlinked tendencies are mostly negative. Carried to the extreme experienced at Gezira under its former "joint account" system, it can mean farmers are forced to grow the scheme's main crop at a loss. These distortions are sufficient to a strong case for switching to some other method for cost recovery. Chapter eight notes this is the major challenge facing the designers of irrigation schemes. We do not have an answer to propose, but feel this is where comparative irrigation research should focus.

Ballooning Overhead Costs - There is little need to repeat here the analysis contained earlier in this chapter about the likely reasons for poor cost control in African irrigation parastatals (illustrated also in the Bakolori Scheme case). The failure of Africa's service agencies to maintain internal cost control is a significant weakness, calling into question whether supervisory agencies are worthwhile. Our analysis suggests the many operational difficulties faced by individual schemes do make a support organization necessary. Because of the very weak technological capacities of the private sector in all but a few countries (notably Kenya and Zimbabwe), privatization is not a viable answer. Technical assistance to individual schemes will continue to be located either within Ministries of Agriculture or in supervisory parastatals of the types described earlier. It is these latter organizations which display inadequate cost control both internally and in regard to the officially sponsored schemes they supervise.

We recommend a three-staged intervention. First, the parent ministry's own project monitoring and program budgeting can be made more relevant and efficient. The Kenya Ministry of Agriculture's experience in adopting microcomputers for budget preparation is one such instance (Wescott, 1986). Second, "performance contracts" for each major parastatal while not a panacea still appear promising (Mallon, 1982). Third, detailed changes in how accounts are handled and how transfer costs are assessed will be required. We stress the great importance of finding systems which give managers an incentive to monitor their own performance and to identify where costs originate.

Absence of Irrigation Engineering - In much of Anglophone Africa other than the Sudan, the tasks which might come within "irrigation engineering" are instead handled either by civil engineers or by agronomists. Irrigation engineering as a coherent professional field is just beginning to emerge as African trainees return from (mainly) overseas professional training. This situation leaves opportunity to devise an experientially-based, African oriented content of the new discipline. The evidence of disastrous decision-making contained in chapter three is ample basis for recommending that the new profession should have a trans-disciplinary perspective. Africa's field engineers must understand, of course, the basic rudiments of construction, engineering design, water conveyance, and crop water needs and application. But given the huge wealth of literature and applied knowledge which this review has uncovered, we think it is quite feasible that they should also learn how to minimize adverse environmental impacts; the micro-economics of existing production systems; how to work alongside and communicate with farms; and basic managerial skills. If irrigation projects must be financed and built within a project cycle framework, then irrigation engineers must understand the likely "downstream" impacts of a socio-economic and managerial nature at the time when projects are being negotiated and established. Other specialists who might be better prepared to undertake this task are unlikely to receive the opportunity.

The Lack of Irrigation Extension - Chapter ten deals with the nearly total absence of irrigation extension in sub-Saharan Africa. The irrigation management literature tends to view farms from a "top-down" perspective, as if their proper role is simply to carry out operations according to instructions. It can be noted to the contrary that farmers have their own priorities not considered in scheme planning. They choose what crops to grow, where and when to work, which laborers to employ, how water will be applied, and whether they will contribute to maintenance and on-scheme investments. These are key inputs which cannot be effectively mobilized unless two-way communication exists between technicians and farmers. Thus we consider that the evolution of better irrigation extension in the modern sense of a joint undertaking between farmers and advisors should be a high priority for irrigation managers.

Improving Irrigation Management

There are several highly structured interventions developed elsewhere which are increasingly recommended to African governments to improve local irrigation performance. Among them are:

- quantitative modeling of the hydrological system;
- increased pre-service technical training;
- increased training in project appraisal;
- the World Bank's "training and visit" extension system;
- implementation of community-managed systems; and,
- introduction of Asian "green revolution" crop varieties.

Policy makers should have at least two major reservations about the likely effectiveness of an uncritical transfer of external technologies (scientific and managerial) into African practice. First, the components these technologies address may not be in fact the limiting factors within Africa. Where so many essential components are missing it becomes quite unlikely that concentrated assistance to any single element will be sufficient to boost overall productivity. Instead, a balanced effort directed towards remedying the more obvious weak points would seem a better use of scarce external resources (see above and in chapter ten).

Second, the highly structured and procedural character of the proposed interventions greatly reduces their impact when they are implemented in settings which do not meet the implicit preconditions. Humpals' review in chapter five of the disappointing performance of Asia's high yielding rice varieties in Africa illustrates this point. An equivalent managerial example concerns the World Bank's current promotion of its Indian-derived "training and visit" extension system within the parts of Africa covered by this review, e.g., the Gezira in Sudan, central Kenya, and Northern Nigeria.

The "training and visit" (T & V) approach was initially developed in Turkey and then further modified in India (Moris, 1987). Its Indian success was achieved in communities where farmers who already enjoyed good commercial input supplies and subsidized irrigation water were introduced to higher yielding varieties of their preferred crops. The varietal "packages' were the fruit of over a decade's intensive research on externally assisted agricultural universities and experiment stations. Furthermore, farmers lived in densely settled villages which enjoyed reasonably efficient administration. Proponents of T & V extension have, however, attributed Indian farmers' rapid takeup of the new varieties to a system for intensified field training coupled with regularized farm visiting developed by Daniel Benor. While even this conclusion can be challenged from Indian evidence, it is a much more serious contention to propose the loan-financed introduction of T & V methodology to achieve a breakthrough in African irrigation farming. Take, for example, farmers' situations in northern Nigeria (described in chapter three). Here the wheat farming promoted by the government competes with farmers' own preferred guinea corn; it involves varieties not suited to the hot tropics; input suppliers are scarce and unreliable; and it uses some of the world's most expensive irrigation water. For various additional reasons beyond the scope of this report, we cannot recommend T & V extension as an initial approach to increasing irrigation efficiency (Moris, 1987).

Africa's irrigation parastatals have been slow to make use of formal training as a means for improving either their own output or scheme and farm-level irrigation. Manpower planning for the sector has been almost entirely absent, as already noted. However, the situation has begun to change. SAED is establishing its own central training program, and there are no doubt other instances unknown to us. It is obvious that the physical control of water does require considerable technical understanding at the point of application. One thinks immediately of the operation of gates and pumps, the reading of flow gauges, the timing of irrigation, use of siphons, location of control structures, gradients, infiltration rates, and so forth. On some African schemes farmers have not yet learned how to use siphons, and destroy the furrow walls each time water is let into a field. On others there is evidence of persistent overwatering, despite the high expense of obtaining irrigation water. These seem to be kinds of knowledge which can be conveyed in formal instruction, though preferably offered in a "hands on" setting.

There are several institutions now assisting in international irrigation training. Within the USA, Utah State and Colorado State Universities have each developed short course training aimed at Third World irrigation managers, as have also Silsoe College in the United Kingdom and no doubt others in Holland and Israel. Most of these came institutions offer M.Sc. work on irrigation and water management. A spin-off benefit has been the development of instructional modules on irrigation management targeted to third World audiences (cf. Utah State's 40 "Ecuavir" slide-tape units developed initially under contract to USAID/Ecuador). In the U.K. and in Zimbabwe, Wright Rain Ltd. has been developing computer-based advisory services to guide in the selection of particular techniques. One can foresee the further evolution of computerized "expert" systems to guide project designers.

At present, such interventions probably do not greatly influence irrigation management competencies in Africa. The amount of training being done is still miniscule in relation to potential demand. Furthermore, there is nobody in a position to target the training "package" to suit local constraints and needs. The three groups who are involved--subject matter specialists (engineers, agronomists, etc.), method specialists (audio-visual experts, extensionists, etc.) and local pressure groups (ministry officials and parastatal staff) reap the benefits from external intervention irrespective of whether the training is relevant and effective. On balance, most official training as provided either internationally or locally within Africa is probably counter productive to the achievement of its intended objective of building local managerial capacity (Honadle and Hannah, 1982). We would guess that jointly sponsored short courses conducted in developing countries but assisted from abroad, such as Silsoe's four-week course on irrigation management offered in Swaziland's Mananga Agricultural Management Centre, may constitute a partial exception to this criticism. Perhaps new approaches such as the problem-oriented training described by Peuse and Mbaga (1987) or the ILO's "guided transmission training" (Donarski, et al., 1983) would increase the effectiveness of training interventions. Even so, trainers should recognize that malfunctioning managerial system can absorb large amounts of external training without positive effect until the system itself is remedied.

What reforms should African governments consider, given the generally disappointing field performance of irrigation technologies?

1) We strongly support any interventions which would make scheme staff more accountable to the farmers they are supposedly serving.

2) There is an obvious case for diagnostic analysis and training dealing with maintenance management (see chapter ten).

3) Sociological assistance should be sought to learn how to fit diverse family types at different stages of their household development cycle into standardized scheme settings.

4) Experimentation in devising houseplot tenure and farming including a horticultural element separate from the irrigated field system is long overdue. In general, irrigation developers need to pay more attention to land tenure (see chapter seven).

5) Irrigation parastatals could profit from a review of the management information systems used to monitor scheme performance. The goal should be to simplify scheme record keeping while concentrating attention on key performance parameters subject to continuous monitoring by management.

6) Transfer cost pricing linked to more strategically selected cost centers must be imposed upon irrigation parastatals and authorities, as an emergency measure to identify where cost overruns originate.

7) International comparisons of scheme software, the procedures used to operate different systems, and their impacts upon farm performance would be valuable. Obvious candidates for comparative review include Sudan's Gezira system, SAED's approach to small perimeters, Kenya's Mwea system, and Dutch and Chinese methods of polder management.

8) African field engineers would benefit from a similar exchange of construction manuals and standardized designs between countries, with the objective of finding ones which are robust under low performance administrative support.

9) The frequent delays and cost overruns associated with construction, mechanization, and operation of heavy equipment in African settings need to be examined and either corrected or avoided.

10) Irrigated farming would benefit from use-oriented extension (Peuse and Mbaga, 1987). In its present form, the World Bank's "training and visit system" should be avoided. On the whole, African countries have not yet found how to offer effective agricultural extension under low resource constraints (Moris, 1987).

Finally, we close this chapter by an appeal for the development of a system architecture suited to small-scale irrigation (as outlined in chapter six based on Wensley and Walter, 1985). In the language of public administration, this would involve the adoption of a "learning process" mode of project development (Korten, 1980; Bagadion and Korten, 1985).

CHAPTER TEN

IMPLICATIONS FOR DONORS

Issues

The literature already contains three useful listings of the main issues donors should weigh when appraising irrigation development. Two come from AID-financed studies (Berry et al., 1980; Steinberg, 1983:35-65) and one from the OECD (Carruthers, 1983:68-75). Drawing most heavily on Carruthers, we suggest 15 points on which policy decisions are required in African irrigation:

1. Where and when to subsidize?
2. New projects or rehabilitation?
3. Drainage or more irrigation?
4. Large-scale or small-scale irrigation:
5. Direct investment or price support?
6. Public or private development?
7. Hydro-power versus irrigation?
8. Hardware or management?
9. Conjunctive use of groundwater?
10. River basin authorities versus individual schemes?
11. Scope for alternate energy sources?
12. Swamp-rice versus rainfed rice?
13. Rightholders versus cultivators?
14. Full Control versus supplemental irrigation?
15. Technology transfer or technology development?

Familiarity with the general arguments advanced by Steinberg and Carruthers is here assumed. We have emphasized instead the special features which may alter standard prescriptions when one is dealing with African irrigation. It will also become apparent that there are not many continent-wide prescriptions. On most issues, each country has peculiarities which will require extra attention in choosing an appropriate strategy.

1. Where and When to Subsidize?

The first issue to consider in regard to irrigation investment is, according to Steinberg, "Who pays?" (1983:43). By now, the relevance of criteria for cost allocation should be obvious. We have seen that African irrigation tends to become inordinately expensive, that smallholders cannot afford major capital improvements, that the typical peasant farm is "energy starved," and that African governments cannot assume increased recurrent cost burdens. Furthermore, well-intentioned plans for double cycle cropping, introduced primarily to boost farmers' cash flow as a means of enhancing repayment capacity, are not technically advisable under typical African conditions.

Thus, deciding "who pays" is a core issue which must precede consideration of all others on our list. It is fairly clear that under typical African circumstances irrigation simply cannot pay its own way until the accompanying farming system has reached a fairly advanced stage of commercialization, e.g., supplemental irrigation for Kenyan coffee farms or valley-bottom irrigation on Zimbabwe's large farms. The implication for donors is, therefore, that some element of subsidy is inevitable if a country intends to proceed in developing irrigation. The operational question is then not whether to subsidize, but where, when and with what consequences? If so, a financial appraisal is not enough: a country must also look at the economic costs and returns, both at the enterprise level and for the sector as a whole.[1] Questions to weigh include whether to finance initial construction on a grant basis, leaving the host country to concentrate on financing recurrent costs?[2] Can the nation afford to exempt its irrigation schemes from duty on imported inputs? Should an irrigated cereal crop enjoy a protected local market? What about concessionary food imports? Would rainfed agriculture give higher or more reliable returns from a similar level of subsidy? What aspects can be left for on-farm financing, given that irrigation as presently encountered tends to be highly risky?

2. New Projects or Rehabilitation?

Obviously, in those countries like Niger or Tanzania where the rate at which already developed irrigable land is going out of production exceeds the development of new irrigation, rehabilitation should take first priority. In recent years, this has indeed been the emphasis among most donors. However, experience with attempted rehabilitation shows the issue is not so clearcut:

- Engineering considerations tend to predominate during rehabilitation, when in fact the greatest need may be for "O&M" modifications.

- The need for rehabilitation is usually linked to a lack of adequate maintenance procedures. Unless these can be instituted within the local system, physical reconstruction will effect only a temporary improvement.

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[1] An excellent study which does distinguish between financial and economic considerations, private versus social profitability, and marketing as well as production costs is the five nation Stanford comparison of rice in West Africa (Pearson et al., 1981).

[2] Grant-financed initial construction may, in fact, leave countries in a worsened situation because of their acute recurrent cost constraints. Here see Finney (1984) and the whole literature on this topic.

- Where the main system has been allowed to badly deteriorate, the costs of reconstruction can be just as high as for the building of new schemes.

- The pyramiding of new loans on top of old ones creates a crushing financial burden beyond the support capacity of many schemes.

- If the root cause for failure to do maintenance is a tight recurrent cost constraint influencing the whole system, this situation needs to be diagnosed and dealt with at a policy level first.

Thus, while the balance of effort in Africa probably should be directed towards improvement of existing irrigation, it does not necessarily follow that physical reconstruction of these schemes under external loan financing is what is needed. A carefully done, case-by-case comparative analysis of "O&M" deficiencies which makes rehabilitation necessary within existing schemes would appear to be preconditional before effective remedial measures can be instituted.

3. Drainage or More Irrigation?

This report has argued that rainfall intensities are such in tropical Africa that drainage must be provided alongside any water supply improvements if these are fairly substantial in size. Farmers' lack of equipment and resource constraints make it unlikely they can add drainage works by local effort. A particular technical problem is how to achieve adequate drainage on the very flat alluvial plains in parts of the Sahel, e.g., along the Niger River or near Lake Chad. Elsewhere for the most part existing schemes can utilize the topography for drainage (provided that care is taken in the initial design). Health hazards and removal of weeds from drainlines must also be considered. For all these reasons, drainage and irrigation must be jointly provided and the drainage component may require careful planning.

4. Large-Scale or Small-Scale Projects?

If in Africa small-scale projects are not necessarily cheaper to build, they are nevertheless easier to withdraw from; managerial assistance by an NGO rather than the government is more feasible; they represent a smaller financial commitment; field layouts can be more adapted to farmers' needs; and there is at least a theoretical possibility farmers will be more involved and consequently more committed. We recommend, therefore, a bias towards assisting small-scale projects and technologies, traditional as well as modern.

This recommendation is qualified by reservations outlined in earlier chapters, and also touched upon by Carruthers (1983:70-71). It ignores the fact that schemes requiring large reservoirs or major canals are bound to be large-scale in nature. It also conflicts with a pervasive opinion within AID/Washington that small projects are just as demanding of supervision and management as are large ones. While this may be true, the consultants drawn upon in this study were nearly unanimous that in Africa smaller, flexible projects on average outperform the larger ones. One final point: these arguments do not rule out experimentation within large systems to decentralize scheme functions and increase farmer participation, e.g., as the Dutch have attempted in the Office du Niger.

5. Direct Investment or Price Support?

Carruthers warns that for irrigation to succeed, agriculture must be profitable (1983:71): "There is clearly no point trying to enforce water charges or other taxes if farmers do not have a reasonable income." He outlines a downward spiral where governments try to maintain low food prices while maintaining over-valued exchange rates and imposing inefficient bureaucratic controls on agricultural production. When production stagnates, the availability of cheap food aid on concessionary terms removes the pressure to allow a raise in farmgate prices. The dangers of this situation are by now well recognized (World Bank, 1981; Bates, 1981), particularly within USAID. (However, if we accept this argument at the farm level we must also recognize its validity at the country level, where adverse terms of trade vis-a-vis the industrial nations have a great deal to do with the current difficulties of African commodity procedures.)

The central economic issue remains how to introduce irrigation technologies in systems where because of very small farm sizes and low productivity farmers cannot individually afford expensive capital improvements. This explains why so many countries have introduced intermediary institutions whose service charges in turn depress farm prices. While better prices might raise the ceiling on affordable investment slightly, the gap between smallholders' existing technology and what outsiders might recommend continues to be very wide.

6. Public or Private Development?

Carruthers is probably correct in insisting that irrigation development is one sphere of economic activity where both public and private initiatives are required (1983:72-73). This message will not satisfy either side in the continuing debate over "privatization," incentives and bureaucratic reform. The situation is further complicated because in Africa here "private" does not describe a unimodal cluster of firms. Instead, as a rule the "private sector" in African countries is sharply bi-modal, being split between traditional small-scale farming (and trading) and large-scale, export-oriented "plantation" agriculture, as often as not owned by outsiders. A third group are the missionaries and other NGOs, oriented toward smallholders rather than the plantation crop sector.

While large-scale operators may cooperate with public agencies in sharing experience (something we recommend), their scale of operations is so much larger that on vital managerial aspects they have little that is suited to the smallholder. As noted above, this disparity explains why many African governments of all ideological complexions have been forced to establish intermediary service organizations to assist irrigated smallholder farming. Furthermore, most activities needed for developing irrigation--testing of materials, design of new systems, modeling of aquifers, integrated planning of groundwater and surface supplies, controlling of saline intrusions--are not activities the private sector will underwrite (Carruthers, 1983:72). Nor are the individual African regimes eager to see non-national firms play a larger role by being given privileged access to credit or preferential donor assistance. Thus, AID/Washington's policy mandate to give greater assistance to the private sector runs directly counter to local political realities in many ex-colonial African nations. To the extent that "aiding the private sector" will mean giving assistance to outsiders (e.g., Lebanese in West Africa or Asians in East Africa) or even to tribal elites, it often cannot become a stated policy. A possible resolution would be to encourage activities which deepen institutional resources (training, research and extension) available to the whole irrigation subsector.

In regard to small-scale operators, AID has much greater flexibility for rendering support, but comparatively less to offer because such systems are so different from our own. There appears to be a genuine "technological gap" at the micro-irrigation end of the spectrum, where farmers are irrigating market gardens from very limited supplies. As a donor, AID could also underwrite credit for small-scale operators--though this should be linked to training because of high risks and frequent failures. AID could do much more to insure technical backstopping for various NGO, PVO and Peace Corps projects active in small-scale irrigation. An assessment of "technology backstopping" needs for small-scale NGO projects might be a suitable topic for an all-Africa workshop.[1]

7. Hydro-Power-versus-Irrigation?

Hydro-power generation and irrigation needs can come into competition in several ways. If irrigation is developed upstream from power generation, the loss of water can necessitate a significant reduction in hydro-power generation--as, for example, Tanzania's irrigation schemes in Mbeya Region above the Mtera and Kidatu dams on the Ruaha River. Where power generation lies on the upstream side, the need to maintain flow even in the rainy season will reduce water storage available for dry season irrigation. But much of the most important interrelationship concerns the cessation of annual flooding on rivers where this may have been significant to farmers, e.g., the Aswan High Dam on the Nile (Waterbury, 1979). In West Africa, on the Senegal and Niger Rivers, farmers practiced "décrue" (or "recession") farming, planting their crops on river terraces as the floodwater receded. While not

[1]AID policy on the public versus private issue is discussed at some length in Steinberg (1983:57-60).

"irrigation" in the strict sense, this tradition made maximum use of scarce moisture and existing clay soils in an otherwise barren environment. It is sufficiently important that the new upstream dam on the Bafing River (a major source of the Senegal's flow) has been designed to provide an artificial "flood" through controlled water releases. For similar reasons, some have proposed that Tanzania's Steigler's Gorge Dam (not yet financed should also allow for downstream flooding in the Rufiji Delta (Sandberg, 1974). In either case, the artificial "flood" will lack the sediments which are mainly deposited in the reservoir's upper end.

One might question spending time on this issue when throughout this report large projects have been downplayed. However, three added facts are relevant. First, the tradeoffs between hydro-power, dry season irrigation and "décrue" (or equivalent, downstream pump) farming are a significant issue in three countries high on USAID's priority list (Egypt, Sudan and Senegal) and also in systems which derive their water from neighboring countries, e.g., Somalia and Mozambique. Second, Africa has tremendous though underdeveloped hydro-power potential. It would be very helpful to have worked out in detail the interrelationships between power generation and agriculture before further large schemes are launched. Third and perhaps most appropos to this report, it is discouraging to see high voltage transmission lines passing right over irrigable lands in countries where water pumping still depends on diesel engines. Hydro-power in Africa has largely been used for industrial development, not irrigation. Since the continent does have such large reserves of untapped hydro-power potential, the present energy constraints within irrigation ought to be viewed as an inheritance from the past and <u>not</u> a constraint upon future development.

8. Hardware or Management?

Many think this is <u>the</u> overriding question to be addressed in African irrigation. It is difficult to answer, because the usual means donors employ to gain influence over project management is through financing increments to "hardware." Without building new schemes, would donors be allowed to assist on "O&M" issues? In Africa, the answer might well be "yes" for the simple reason that Ministries of Agriculture find themselves hard pressed to plan and supervise irrigation development.

In the section on irrigation management, seven types of "software" were identified as potentially contributing to the effectiveness of irrigation in Africa. Not all are operational at the moment--which partly explains glaring gaps and weaknesses in many of Africa's present schemes. Let us recapitulate what the seven types of management include:

1. Sector planning and supervision;
2. The construction stage;
3. Scheme management;
4. Main system management of the water supply;
5. Supervision and liaison with water users;
6. On-farm water management; and
7. Environmental impact management.

Of these seven levels, some type of "software" (i.e., organizational routines) is definitely required at each level. Nonetheless, few authorities on irrigation recognize more than three or four. Because of this particular problem encountered in Africa, irrigation advisors need to become cognizant with all seven.

A principal message of this report has been that these levels are rarely considered jointly. Each managerial unit concentrates on its phase in the project cycle in the hope that ultimately crops will be grown and farmers benefit. Indeed, one cannot even tell from the literature on most schemes what managerial practices are in general use. One suspects that as currently implemented, project "management" concentrates on physical construction--always a particularly demanding task in Africa--with "scheme" management coming in once a perimeter is "handed over." Enough is known about field difficulties to suggest that there is very little margin for error.

Field operations under typical African conditions encourages an opportunistic, day-by-day management style which differs greatly from the procedurally complex routines outsiders often recommend. In stating Africa's need for better "software," we are not implying that the "high technology" routines coming into vogue among US irrigation engineers represent a good, or even workable, solution. Instead, the argument is that the managerial sphere must be where attention is concentrated in an effort to learn how and why existing systems "go wrong." Only then can one select among "software" options and design more effective forms of training.

9. Conjunctive Use of Groundwater?

Where water supply from flowing rivers is so difficult, the question naturally arises whether instead irrigation should not draw upon "tubewells" (or "boreholes," as they are called in Africa). At a policy level, the answer obviously must be "yes"--but strongly qualified by recognition that pumping has a particularly bad record in Africa and that there may be large areas where the low yield from wells cannot support anything beyond a very small patch of irrigation. However, donors could promote the exchange of experience between those working on household and community supplies, often based on pumping, and the irrigation sector in the same country. European donors such as SIDA and the Dutch have put heavy investments into development of community supplies in Africa, and have accumulated valuable experience.

10. River Basin Authorities versus Individual Schemes?

We have noted that many African countries have created river basin authorities responsible for planning water resource development. The degree of executive involvement varies, ranging from those like Senegal's SAED, carrying direct operational responsibilities for small-scale projects, to those with purely planning functions like Tanzania's RUBADA (for the Rufiji Basin) or Kenya's TARDA (for the Tana and Athi River

Basins). The prior existence of such agencies gives an additional option to donors interested in assisting African irrigation. In many countries, donors have three basic possibilities; (a) assistance to individual field projects; (b) support to the irrigation section in the Ministry of Agriculture; or (c) support to one or more river basin authorities (RBAs). The policy issue then becomes to determine under which circumstances irrigation agencies, ministry units, river basin authorities, or individual projects merit which kinds of assistance? No general answer applicable to all of Africa is possible. The priority placed on irrigation differs from country to country, as do the levels of performance shown by outwardly similar organizations. One can, however, identify the advantages and disadvantages of assisting the RBA-type units.

The principle advantage is the fact already noted that RBAs are often the only administrative units which already possess a rudimentary irrigation planning capability. If an aim of assistance is to deepen in-country technical capabilities, then the TBAs constitute a feasible starting point. Most are parastatals, and as such, have better changes to attract and retain specialized staff. Irrigation planning is usually already within their formal scope of operations, so that complicated negotiations and new legislation are unnecessary.

The RBA orientation towards planning can also become an obstacle, if it becomes an end in itself or if inappropriate methodologies are adopted. Vincent (1984:28) warns that American concepts of river basin planning can be quite detrimental in an African context. And, one might add, very expensive: development agencies can develop an enormous appetite for an interminable series of "preliminary investigations."

In view of the latter danger--which African experience indicates is quite real--we suggest that AID might concentrate on developing more appropriate and cost-effective training and research methods for RBAs. Among these might be:

- Training at a Master's level in irrigation-related fields;
- Regional or Africa-wide seminars to direct attention to new concepts, procedures and resources (e.g., farmer participation, remote sensing applications); and
- Derivation of simplified planning and monitoring techniques which would be more cost-effective under African conditions.

11. Scope for Alternate Energy Sources?

If African peasant farmers depend mainly on human or animal power, and if irrigation agencies have such difficulty obtaining fuel, why cannot other forms of renewable energy be employed? Each of the alternative sources--methane, windpower, solar power, photovoltaics, and even new domesticates like water buffalo--has its adherents. The record so far, however, suggests once again that caution be exercised. Any alternate energy source which itself requires complicated technology is likely to malfunction in the harsh African environment. Similarly, any "appropriate" technology which is vulnerable to neglect or misuse is likely to fail.

In the longer run, it may be feasible to power small-scale equipment from photovoltaics (provided the vandalism problem can be overcome), just as the inclusion of lucinae stands within a surface irrigation system could provide the raw material for biogas generation. A more risky and still longer-run option would be to copy Brazil in using sugar byproducts (ethanol or alcohol) derived from irrigated production for powering scheme equipment. All three options are technically feasible today, but represent fairly high risk possibilities in the more remote parts of Africa (primarily for managerial and environmental reasons). What is clear is that energy costs are problematic, while farm operations remain energy-starved for want of a cheap and readily accessible fuel. Thus, further experimentation is warranted, and meanwhile the calculation of energy budgets (both in the ecological and in the financial sense) ought to accompany any in-depth analysis of proposed irrigation developments.

12. Swamp-Rice versus Rainfed Rice?

Africa has its own traditional varieties of "upland" rice, which appear to have been domesticated within West Africa itself (Harlan, 1985). In recent decades, flood-basin types from Asia have been replacing upland rice in the coastal, West African countries even though proportionately rainfed rice production is still far more significant. Nevertheless, by draining valley bottom lands ("swamps") and switching to wet rice varieties, per hectare yields can be greatly increased. Most state-sponsored schemes have been of the "swamp rice" or valley improvement kind. Since, as we have seen, seasonally waterlogged lands are widely found throughout tropical Africa, the issue arises whether or not valley improvement schemes are as cost-effective as equivalent investment in "rainfed" upland production. At the country level, several USAID analyses have addressed this question--usually in the form of a crude contrast between "irrigated" versus "rainfed" development--with the usual result being to recommend concentration on rainfed production.

In reality, it is not quite so simple. The valley-bottom "vertisols" represent some of the best agricultural land available provided they are intelligently used with suitable technologies. The division between "irrigation" and "rainfed" cultivation is here also arbitrary, since what usually occurs is not full irrigation, but rather a combination of drainage, impoundment (for "wet" rice), and some supplemental water to extend the soil moisture regime. Within individual countries of West Africa one finds a diversity of rice production systems extending along a continuum of gradually increasing investment intensity. While some "polder" type swamp schemes can be extremely expensive, others based on slight modification of farmers' existing technology are not. The Stanford comparison of rice production in five West African nations gave different results for each country and for individual systems (Pearson et al., 1981). We therefore recommend an updating of the

Stanford analysis employing present prices and incorporating additional crops (wheat, sorghum and cotton), while focusing more agricultural engineering attention on the technological issues inherent in valley-bottom improvement.

13. Rightholders versus Cultivators?

Tenure problems arise as an issue because in Africa those controlling plot rights--whether they are bureaucratically appointed managers or male kinsmen in charge of a compound--often cannot provide the labor irrigated production requires. Since this is also true for much of Asia's irrigation, observers may have been slow to recognize its ramifications in the African context. The "problem" exists because in either of the two contexts--scheme of compound--those recognized administratively and socially as rightholders are under minimal pressure to acknowledge cultivators' claims over irrigated land and its production. For example, when irrigation schemes insist upon retaining rights of eviction over tenants, they create a psychological climate wherein the individual farmers will be unwilling to invest in long-term improvement, or sometimes even in canal maintenance. Similarly, if household bonds are weak and a woman anticipates being dispossessed (of either her home or her share of crop returns), she is unlikely to provide the substantial labor input which irrigated rice or cotton requires. There is ample evidence that those doing field work are not utilizing irrigation to the full extent which is technically feasible. While one can guess at their reasons, such guesses constitute an insufficient base for policy formulation.

We recommend, then, that research targeted on this topic be undertaken under various social and technical systems. Furthermore, donors who finance irrigation projects are in a position to insist that procedural changes are made which give greater security to cultivators. It is a strange situation indeed that in rural systems where women had quite strong traditional rights to irrigated food crops, under "modern" bureaucratic schemes they lose these safeguards. Some fairly simply procedural improvements are usually feasible. One could insist, for example, that daughters as well as sons could inherit plotrights; that whoever is in day-to-day charge of the crop can be issued credit; and that houseplots can be owned by families outright (thus safeguarding the value of house improvements). Some countries have already implemented such changes; exchanges of operational experience might facilitate the diffusion of better procedures aimed at increasing household security and intra-household equity.

14. Full Control versus Supplemental Irrigation?

It will be noted that the question usually posed, whether to stress irrigated versus rainfed agricultural development, has not received as much emphasis in this report. Here we suggest an intermediate position makes the most sense. We note that commercial farmers in East and Southern Africa have usually found it necessary to develop supplemental irrigation in order to achieve reliable crop yields. If so, the same need probably exists within smallholder farming. Regularization of rainfed crop returns by stabilizing planting dates and eliminating the within season dry spells might represent a more desirable (and water conserving) objective than "full" irrigation with its heavy water demands. The main problem is, of course, the high cost of present technologies for achieving this objective. Generally, the large-scale farmers in Africa employ movable piping and overhead sprinklers, requiring heavy initial investment. Some suggest that drip irrigation represents an ideal compromise where water is scarce, but here, too, practical difficulties--termites and impure water--are encountered. Perhaps the answer is to incorporate water harvesting during the rainy season; or else to add a rainfed, supplemented crop grown alongside the area used for "full" dry season irrigation. We do not yet have answers, but the need to pay more attention to partial irrigation seems obvious (repeating a point made vis-a-vis "swamp" systems).

15. Technology Transfer or Technology Development?

The final issue is one which underlies many aspects of this review: the selection, adaptation and support of irrigation technologies. Questions which come under this rubric have surfaced again and again in this review. For example, it is clear that some irrigation techniques must be accompanied by certain technological capabilities (e.g., freedom to import parts or access to streamflow data) before they can be used effectively. But which ones depend upon which "upstream" support capabilities? Again, when should African governments accept "orphaned" equipment imported at donor insistence? (This has been a frequent issue in irrigation because rapid repair is usually essential.) Which aspects of US, Egyptian or Asian irrigation experience can be transposed directly into African practice? Are there "miracle" technologies (like drip irrigation) which might dramatically improve output within African irrigation? Can systemic weaknesses at the local level be offset technologically by increased investment? Why are even simple technologies like pumpset operation so problematic in rural Africa? Can given technological packages such as Dutch polder techniques be disaggregated and employed selectively? When and where should donors sponsor technologies which are new to Africa, such as overhead sprinkler irrigation or satellite-based "early warning" systems?

Whatever one might conclude theoretically, such questions are at present answered largely by default. Particular donors almost invariably stress the kinds of technology already in use at "home" or developed in their former colonies (e.g., the "Gezira" system). It is clear that for the large-scale commercial producers who enjoy exemption from currency restrictions, the standard "off-the-shelf" solutions from advanced nations usually can be made to work under highly standardized, plantation crop situations. However, as soon as one must deal with typical smallholder situations in the more remote communities, technologies tend to become quite problematic unless carefully adapted to circumvent local constraints. The adaptation and support elements are often overlooked in programs aimed at direct technology transfer. Since irrigation is essentially a repetitive activity, involving a network of support institutions, we recommend that donors put greater stress on deepening local technological capabilities.

Gaps

The scope of work for this overview specified that it should identify priority areas needing further attention--the "gaps" within present research or within the existing distribution of institutional effort. What are, then, the most significant missing elements whose lack contributes to the present low efficiency of Africa's irrigation?

1. Irrigation Engineering

At several points in this report it has been pointed out that irrigation engineering in the American sense is absent from black Africa, except perhaps the Sudan and Sahel. When tasks requiring irrigation expertise arise, decisions tend to be made either by civil engineers (at the design and construction phases) or by agronomists (in scheme operation and water management). Few of the civil servants who staff Africa's river basin authorities and ministry-linked irrigation units are actually professional irrigation engineers. Most come to their assignments from other professions, and see themselves more as employees of the agency than as irrigation managers *per se*. As a consequence, the handful of qualified irrigation engineers in each country will be preoccupied in dealing with donors and reviewing new projects. While the manpower gap is being gradually closed by recruitment of newly trained professionals, "irrigation engineering" does not yet exist as an integrated field combining elements of design, construction, water management and agronomy within a single discipline.

On the one hand, this situation leaves room to shape the emerging discipline in ways more suited to Africa's needs.[1] On the other hand, it also explains the technical void encountered in most countries on matters related to water management. Without enough trained professional staff, African irrigation agencies rely heavily on outside consultants and on accidents of bureaucratic precedent to determine their managerial systems.

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[1]In-country programs for training irrigation engineers constitute an obvious area where fairly modest donor commitment might have major long-run impacts. If we look at numbers being trained, Egypt is at present by far the largest source for African professional manpower in relation to engineering and irrigation (FAO, 1984).

2. Manpower and Sector Planning

Few African countries have in hand systematic plans for the strengthening of manpower support for irrigation development. Most have never analyzed staff needs in the irrigation subsector, nor do they have accurate or even up-to-date statistics describing the sector. Sometimes, as in Kenya, individual units have good documentation, but the overall effort is badly fragmented. More typically, as in Somalia, the necessary information for irrigation planning is simply not available and no realistic program for staff preparation exists. Of course, staffing weaknesses go hand-in-hand with an absence of sector planning. As a consequence, in most countries technical design and even field supervision depend on donor-financed, expatriate staff who leave when their contracts terminate. We have pointed out that this situation greatly reduces the possibility of organizational learning taking place within local agencies officially responsible for irrigation. Even after two decades of external assistance, many African countries have surprisingly little institutional capacity for planning and managing their irrigation subsectors.

3. Project Documentation

For African irrigation, the "literature" such as it is consists mostly of project documentation[1]: preliminary reviews, appraisal reports, design specification documents, donors' performance audits, a sprinkling of trip reports, terminal reports and project evaluations. For most larger projects, several consultancy firms will have been involved. Their reports are user-commissioned. Sometimes individual authors rework their data for academic publication, but much more commonly the reports can only be found in the firm's headquarters or stacked against the back wall of some minor official's office in the recipient agency. Officials receiving this documentation have no incentive to integrate the information into a larger picture; and, indeed, the site and project-specific format makes synthesis difficult. In many African countries, the only general collections of such technical materials occur in donor's offices, particularly within USAID and the World Bank.

This background accounts for the thinness of U.S. documentation on African irrigation. The two principal exceptions are U.S. theses based on African field research and the World Bank's home office collections (to which access is usually restricted). For the bulk of materials on African irrigation, one must travel to company offices in England and on the continent or to library collections in Germany, Holland, London, Paris and Rome where the larger volume of donor-financed activity has originated. In particular, we suggest that there is a need for an inside review of documentation held in the United Kingdom, since British consulting firms have been especially active in Africa.

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[1]For an annotated bibliography of recent sources, see Volume III of this report.

4. Vertisol Management

Vertisols--what a lay person calls "black cotton clay soils"--are found throughout the tropics, wherever soil formation occurs under circumstances of impeded drainage. Such soils constitute an important resource because of their moisture retaining capacity and their differential fertility, not only in Africa but also in India and Brazil (where they are also significant). In the review of technical aspects, it was pointed out that while these soils are difficult to work with light equipment, they are nonetheless the site for most flood basin irrigation of rice in Africa. Depending on the situation, they may be either acidic (highland swamps and coastal mangrove swamps) or alkaline (saline "pans" in closed drainages). The main point is that they react to moisture very differently from the sandy loams prized by plough farmers. With vertisols, canal lining may be unnecessary--a significant advantage in Africa--but water control structures must be specially constructed. Also, their high moisture retention may permit preirrigation and the growing of a subsequent, "ratoon" crop. For all these reasons, while vertisols constitute a key resource they require distinctive engineering and agronomic management. Individual African countries are rarely in a position to tap the continent-wide experience with such soils. We suggest that donor support for exchange of managerial experience coupled with further research to identify the most cost-effective crop and equipment combinations, would be something AID should consider. Any such exchanges of experience should also draw in irrigation engineers from Egypt, India and Brazil.

5. Weed Control

An unexpected finding has been that control of weeds--terrestrial as well as aquatic--is a major difficulty within African irrigation. Terrestrial weeds are, of course, usually treated as a farm-level problem, whereas aquatic weeds are seen as a threat to the water management system as a whole. Nonetheless, both types pose a high level of threat to irrigated production. Without repeating the technical arguments about "red rice" and other common weeds, we note simply that the partial completion of scheme works which often occurs provides ideal circumstances for rapid weed growth, just as tropical canal systems do for aquatic weeds. More attention to this aspect is imperative, since there are good reasons for suspecting that under typical conditions for smallholder production the degree of weed challenge may be far greater than is commonly acknowledged.

6. Maintenance

If, as earlier WMS II studies suggest, physical rehabilitation is in effect the provision of "deferred maintenance," then it seems plain that maintenance has been the weak link in many African irrigation schemes. The resulting deterioration is evidenced by inoperable equipment, by weed-choked canals, and by the erosion and failure of physical works. To the outsider, it seems poignant that expensive irrigation works should be allowed to deteriorate so rapidly in such poor countries. Tractors and pumps which could have served for ten years may have an average working life of two to three years. Some schemes now require rehabilitation before their original loan financing is half repaid. Observations of this nature explain the nearly unanimous agreement that poor maintenance constitutes the single most important unresolved problem in African irrigation. Of course, it is linked to many other issues: recurrent cost constraints, the impact of currency and import restrictions, farmers' alienation or insecurity, improper design, seasonal bottlenecks in labor supply, etc. We reiterate, therefore, a plea made in last year's review of Sahelian irrigation: that this topic should receive top priority within any field research that donors might finance (Moris, Thom and Norman, 1984).

7. Irrigation Extension

As a rule, either irrigation "extension" is derivative from scheme requirements and confined to the project/scheme environment (as in Gezira, the Office du Niger, or Kenya's National Irrigation Board's schemes) or it is totally absent, leaving a void between the water supply section and the usual, rainfed farming orientation of the general extension service (as in Somalia). To irrigate successfully in Africa, farmers require a number of specialized skills: knowledge of how to level their fields, the signs of moisture stress in plants, when to stop watering, control of salinization, interactions between watering and fertilizer use, how to avoid waterlogging and unnecessary erosion, synchronizing irrigation activities with rainfed farming, how and when to do maintenance, the rotation system (if practiced), signs of nematode buildup, and how to recognize and control weed growth. This incomplete listing is sufficient to indicate that there is a fairly large element of skill and local experience needed.

Farmers who have grown up within an irrigated farming system (such as in Gezira or Madagascar) probably acquire most of the necessary skills informally. Elsewhere on the continent, to the contrary, adult farmers who in other respects know a great deal about plant husbandry may nonetheless lack these special skills. Where initial extension and training has been weak, farmers become entirely dependent on scheme management for advice, and they are likely to perform certain key operations (like field leveling) so poorly that yields are greatly depressed. This situation in turn reinforces stereotypes held by managers and staff about farmers' low motivation and interest, setting in motion the issuance of unexplained directives which further depress farmers' performance. The need for advance instruction is particularly great when irrigators are former pastoralists, whose traditional way of life differs at most from what is required in irrigated farming.

Hardly anything is known about the actual content of "irrigation extension" as it occurs in Africa. There is an urgent need for comparative data of this nature, since the World Bank is willy-nilly imposing its India-derived "training and visit" system on most African countries which accept its financial assistance in the irrigation sector.

8. Intra-Household-Economics

Identification of household economics as a "gap" may strike African specialists as strange, since there is a huge literature on the continent's systems of production and exchange. There are even a number of detailed sources on the role of women in African peasant farming. The "gap" is not, therefore, a lack of basic sources, but refers instead to failure to integrate and apply this knowledge within analyses of irrigated farming. In part, there is a gap if we are interested in detailed economic analysis of the irrigated subcomponents within larger arable farming systems. However, there also appears to have been deliberate blindness towards likely production costs, since to have accepted realistic estimates would have wiped out the apparent benefits which were being claimed for irrigation projects. Incorporation of more realistic figures on likely yields, labor costs, time scheduling, etc. would have made it clear that most African irrigation projects have been problematic right from the start.

To understand future irrigation performance, donors must become willing to incorporate actual field data reflecting typical conditions into project appraisals and evaluation. In systems where households are loosely integrated, allowance must be made for the possibility that returns within the household unit may be insufficient to guarantee the necessary commitment by women and other farm laborers. Analyses must also take into account the opportunity cost of farm labor during the peak bottlenecks so characteristic of African hoe cultivation. Planners must recognize women's strong commitment to achieving food security, and their limited access to credit which forces them to give priority to low input, rainfed cultivation even under conditions of high risk. In short, there are a bundle of agricultural economic issues which require knowledge of patterns of internal household organization within African farming systems. While many of these relate specifically to the women's sphere, there are also other aspects of a more general nature requiring similar data. Estimation of farm investment potential, labor costs, livestock economics, locational economics and intra-household distribution requires a type of applied household economics which is not yet available for most settings where irrigation might be considered.

9. US-Based Irrigation Expertise

The thinness of US documentation on African irrigation is matched by equivalent weakness in regard to irrigation expertise. There are only a handful of practitioners in the USA with professional interests in the various aspects of African irrigation. It was anticipated that there might be few US irrigation engineers interested in Africa, but in fact, irrigation economists are just as scarce. Yet, paradoxically, one finds numbers of younger scholars eager to work on applied aspects of irrigation development--individuals with the necessary field acquaintance and language skills, but usually lacking technical training in irrigation or sufficient support to maintain an active involvement.

Given the lack of senior specialists, it is apparent that AID's future programs will depend upon expanding the numbers of younger professionals in irrigation-related fields. We strongly endorse the concept of "tag-along" assignments, whereby younger workers are funded to accompany the few senior experts on applied assignments in Africa. Another option might be to initiate an exchange program, wherein US graduate students lacking field experience might "fill in" at the host-country level for nationals who come to the USA under long-term training arrangements. Still another need is for establishment of two or three US centers where there is adequate documentation and staff background to provide relevant short and long term training oriented towards African water management.

The difficulties we have encountered in assembling this report from (mainly) US sources will also apply when efforts are made to train African nationals within the USA. It is clear that US institutions have not paid much attention to African irrigation, and have relatively little to offer when it comes to an integrated, relevant perspective. To give adequate managerial training always requires having at hand a wealth of materials related to the problem: case studies, exercises, description of field constraints, etc. At present this context relevant to African circumstances is missing within US technical training, which instead perpetuates a bias toward further specialization and "high technology" solutions.

AID Strategy

The message our review holds for AID/Washington may at first glance seem contradictory. African countries face increased reliance on irrigation in the future, and--in view of the low levels of present performance--have an urgent need to learn how to use irrigation technologies more cost-effectively. Nevertheless, because in most African countries USAID has become a minor donor, we cannot recommend any dramatic increases in AID's direct financial support to underwrite new irrigation projects. Existing African irrigation projects are simply too expensive to warrant receiving scarce investment funds from a small donor. This conclusion is strongly supported by the background papers prepared independently by Vincent, Humpal and Sparling. It also echoes the World Bank's "Berg Report" (1981:78), and Carruthers' OECD review (1983:15), both of which recommend an initial concentration in improving output from present schemes rather than upon starting new ones.

Instead, the consensus among nearly all expert observers is that first priority within the irrigation subsector should be to strengthen its institutional capacities. As a general strategy, this has the advantage of providing a base for future project funding while also assisting countries to get higher returns from already committed projects. In a few instances where a country is heavily dependent on its irrigation sector (as is Sudan and Somalia), the US Government may find it politically desirable to intervene at the production level, but even in these cases we recommend AID moves cautiously. At present, the USAID system in Africa, both at regional levels and within country missions, simply does not have enough qualified irrigation engineers to plan and supervise an expanded portfolio of irrigation projects. An immediate area for attention should be to expand US technical capabilities for dealing with irrigation and water management issues in African contexts. Thus, improvements in "institutionalization" are needed in the USA itself as well as in recipient nations.

By "institutionalization," what is meant? Basically, "institutional" measures are those which increase the capacity of national, regional and local systems to use irrigation more intelligently. More effective irrigation planning, based on actual field information and realistic premises, is one obvious requisite. Ways must be found to stimulate feedback from the farm and scheme levels. Decision-making procedures themselves need revision, so that once problems are identified they receive prompt and effective remedial attention. An organized capability to provide specialized assistance when individual schemes need help must be created. And, of course, projects must be institutionalized at the local level so that scheme users--the farmers themselves--understand what is required and participate to insure the success of their own irrigation.

In reviewing how AID might best render such assistance, we have kept two limitations in mind. First, over the past two decades USAID in Africa has paid little systematic attention to support for irrigation. Very little of value can be found in AID's Washington-based documentation service on African irrigation. When US firms have been active implementing irrigation-related activities (mostly in the Sahel), they have as likely as not employed French Canadians or European engineering staff on those aspects requiring detailed African experience. For East and Southern Africa, USAID has neither the engineers nor the documents required for an upgraded program of institutional support. We must therefore be realistic in assessing which are the areas of comparative US advantage, recognizing that on some desirable topics the US has little to offer. Second, except in a few countries, it is quite unlikely USAID will ever serve as the major donor assisting irrigation. Among other donors, the Dutch, Germans and Japanese are already far ahead and will likely remain so. This situation makes it desirable that AID coordinates its input to take into account what other donors are already doing within the continent. It also suggests we cannot rely upon "spin-off" benefits (participant training, etc.) from USAID's present projects to meet the main need for institutional strengthening. If this becomes AID's goal for the irrigation subsector, it must be addressed directly.

Taking the above limitations into account, we propose nine options as suitable areas for immediate AID support:

1. Cooperation with Other Donors
2. Incorporation of Irrigation into FSR Projects

3. Systemic Malfunctioning and Rehabilitation
4. RBAs and Irrigation Planning
5. Remote Sensing Applications
6. Women-in-Irrigation-Development
7. Small-Scale Systems
8. NGOs and the Private Sector
9. Deepening of US Capacity

1. Cooperation with Other Donors

In the short run, AID needs to incorporate the experience of other donors which have been active in assisting African irrigation. In saying this, we do not imply that these countries necessarily have better water management expertise than does the USA. The point is simply that documentation on irrigation consists largely of project reports of one kind or another: appraisal estimates, site surveys, trip reports, managerial audits and terminal evaluations. Such materials are usually commissioned, and rarely find their way into academic collections outside the country where they occur. In Africa, the main donors have been the World Bank, FAO, France and England; supplemented in recent years by the various development banks and funds and newer donors such as the Dutch and Germans. To consolidate Africa's present experience with irrigation, one must start with the agencies and donors who have been doing actual irrigation projects--and that means going outside the USA (with the World Bank's Washington headquarters being the one notable exception).[1]

Beyond talking to those who have implemented irrigation in Africa, AID should reach a policy decision to participate vigorously in various low-level, multilateral activities which are already under way. For instance, FAO and the Dutch have strongly supported small-scale irrigation in Africa (Underhill, 1984), and FAO is taking the lead also in analyzing women's participation (Dey, 1984). Both kinds of activity merit additional support, and would constitute excellent starting points for a collaborative effort. AID should strengthen its representation at the various regional conferences on irrigation, which have become more important as the number of donors and potential recipient nations have increased. Assistance might also be given to ODI's irrigation network, which has reached a size where to remain effective it must have additional resources. None of these initiatives seem very glamorous, but they have the advantage of bringing US technical personnel into contact with those involved on a day-to-day basis in the planning and field implementation of African irrigation projects. Another source closer to home is the World Bank, which despite its policy pronouncements, remains closely tied to a number of large investments in African irrigation. While liaison between the Bank and AID in Washington has been smooth, for

[1]Our inability in this study to tap these other sources--except for those in France, which were visited--was a serious limitation, which probably reduces the general applicability and validity of our conclusions.

irrigation expertise the Bank has generally drawn on non-US sources. One way or another, AID and its associated contractors must develop direct access to an experiential base on African irrigation before other forms of institutional support become feasible.

2. Incorporation of Irrigation into FSR Projects

Currently AID has under way several farming systems research (FSR) projects in Africa (in Sudan, Tanzania, Malawi, Ruanda, Burundi and Botswana, among others). The rationale for these projects has been the need to identify existing constraints and to describe the needs of various farming systems. Similarly, ILCA has sponsored several in-depth investigations of the role of livestock enterprises within the larger farming systems (with regional centers in Kenya and Mali as well as in Ethiopia itself). Then, under AID funding CIMMYT has its East and South Africa program, based in Nairobi, but conducting farm-level diagnostic surveys and seminars throughout the region.

Irrigated production exists as a significant option in many of the countries where FSR research is being done. The failure of researchers to give it explicit consideration probably stems from the fact already noted that irrigated enterprises are often only a subcomponent within larger-non-irrigated systems. Also, early FSR research was preoccupied with rainfed, arable farming to the extent even of ignoring livestock enterprises which were also often present. We suggest that there is no defensible reason for arbitrarily excluding irrigation and livestock aspects from FSR, even in systems where these various enterprises are not tightly integrated.

Adding an irrigation component would thus complement existing FSR activities. From AID's standpoint, since these are already funded projects, some finance might already exist which could be tapped; or, alternatively, a minimal startup period would be needed if it were decided to broaden their objectives by additional funding for attention to irrigation and water management aspects. Several specific changes might be instituted along with such modifications: (a) incorporation of more attention to farm decision-making and intra-household aspects; (b) careful attention to competition between rainfed and irrigated enterprises; (c) analysis of the institutional risk which farmers incur when attempting irrigation; (d) analysis of on-farm labor costs and returns, between enterprises and throughout the season; and (e) estimation of returns from different potential innovations. The value of such information for understanding why irrigation has not been popular is obvious.

3. Systemic Malfunctioning and Rehabilitation

A broad review such as this one, based mainly on a literature search, can only provide rough estimates of systemic performance. Numerous examples could be given in earlier chapters to support the conclusion that Africa's irrigation performance is generally far below its design potential. Suggestions were also reviews as to why irrigation has been so problematic, but here the findings are of necessity more tentative. Only a handful of field visits were permitted; field practitioners were, with a few exceptions, not interviewed; and the engineering component is very poorly covered in the available US literature. It would seem essential, then, for AID to further refine the broad conclusions within this report.

Three possibilities for doing so suggest themselves. First, better coverage of individual scheme experience would seem imperative. There are whole countries not covered in this report (e.g., Angola and Mozambique, as well as most of central Africa), just as there are many interesting schemes where the documentation is not available within the USA. Second, it might be fruitful to look at irrigation systems region by region--a task fairly well in hand for the Sahel, but barely begun for Africa's other regions. There are pronounced regional differences which are bound to have direct policy implications; and, in any event, AID's own approach to project monitoring makes use of regional REDSO units. Third, it would be productive to look at particular technologies or situations (lakeside pumping; flood rice cultivation; swamp improvements, etc.) comparatively. (Since these constitute a very large agenda for potential action, we stress the need once again to avoid duplicating what other donors may have already begun.

However obtained, more precise knowledge of the causes of scheme and systemic malfunctioning must be in hand before investments of the usual "institutional building" variety are launched. Public agencies have such an insatiable appetite for conferences, courses, training modules, publications, and the like that we cannot recommend the customary "shotgun" approach to deepening institutional capacity. First, let it become clear what the real reasons for poor performance have been and then begin packaging remedial interventions.

Of course, gaining such information on schemes which are not USAID-funded will be difficult. Descriptions of main system management and present irrigation procedures are almost entirely missing, and must be created from scratch. In the process, it ought to be possible to learn why maintenance is so poor, what skills farmers lack, and the reasons why they are excluded from meaningful participation. Information will also be required on the bureaucratic aspects of agency operation, and on the performance of necessary support institutions in the external environment.

4. RBAs and Irrigation Planning

As already noted in this chapter, AID could focus assistance for irrigation planning within the existing river basin authorities. Here the danger to avoid is to merely duplicate the present pre-investment planning which is already under way for the larger, multinational RBAs like the OMVS. Such projects simply substitute outside planners for local ones; they can become very expensive; and the large number of RBAs opens the door for a never-ending stream of requests. Instead, we recommend AID focus on improving existing methodologies and in-country capacities to do integrated water management planning. Topical attention (conveyed by means of short courses, regional workshops, etc.) might address needs such as development of rapid reconnaissance methods, better integration of soils information, exchanges of experience with regard to vertisols, identification of labor constraints and comparisons between technologies. RBAs might also benefit from manpower analysis and provision of externally assisted training to fill certain priority needs. They are strategically located to monitor environmental impacts, and might welcome assistance to facilitate this important function. In some countries where agricultural engineering has been established within higher level agricultural training, USAID might encourage linkages between training and river basin institutions. Another priority area would be to assist RBAs in evaluating and (where appropriate) organizing technology support to the irrigation subsector. Finally, RBAs should devise their own rating system for measuring scheme and project performance--a development which might serve as a potent stimulus towards better performance.

In all instances, the goal should be to demonstrate an integrated, multidisciplinary approach in practice. Perhaps AID/Washington could select one or two river basins to serve as pilot areas for the application of more flexible, field oriented approaches--maybe the Gambia and Juba basins? (We assume further details about how such a program should be implemented will be forthcoming from AID's parallel review of four African river basins.)

5. Remote Sensing Applications

Until recently, the USA has enjoyed a technological advantage in providing high quality LANDSAT imagery for African natural resource planning. Assuming that the non-military US remote sensing capability remains in the public sector, it offers substantial promise for documenting rainfall coverage, and hence, irrigation demand. Weather satellite imagery has been drawn upon to provide relatively quick overall estimates of moisture and vegetative growth conditions. No other sources can provide equivalent information for such large areas of the continent. We suggest such data should be integrated into a continent-wide "early warning" system, whose forecasts of impending drought would be shared with the countries concerned. In several key countries (from the perspective of US interests) this information, if provided promptly, could trigger a shift towards increased cereal food production in the irrigation sector, e.g., as happened in the Sudan in 1984. There are undoubtedly other applications which also merit further refinement, carried out by collaborative teams of US scientists and host country nationals. One suspects, for example, that spatial and trend analysis of the degree of environmental degradation taking place on the continent will continue to command policy-makers' attention. There is no reason why measurement of broad environmental trends cannot be combined with specific attention to hydrologic aspects. It would be a pity if at just the point where we are learning how to make these technologies genuinely useful, further financial assistance is withdrawn.

The above arguments constitute strong reasons why the US should maintain its present comparative advantage in applying remote sensing to the assessment and planning of natural resources. Of course, should Washington's proposals to "privatize" these publicly funded services be implemented, most LDCs will turn to other non-American sources which are already under development. If, for strategic reasons, the US government must fund such uses of remote sensing anyway, we consider it far preferable that this work is conducted in public where the countries being analyzed can participate and learn from the experience.

6. Women in Irrigation Development

It seems that ultimately many issues in African irrigation revolve around gender-linked differences in farmers' commitment and access to resources. The role of women in African farming is already an academic area where US researchers have a comparative advantage. (One thinks immediately of Simmons, Fortmann, Staudt, Peters, Atherton, Jones and Spring, among others.) We recommend that AID funds a modest "add-on" program targeted specifically at learning how African women participate in and benefit from irrigation. A topical focus on irrigation would give greater practical thrust to AID's present WID commitment, and might constitute justification for added support. The individual studies required would be mostly small-scale, to insure that intra-household aspects receive scrutiny.[1]

7. Small Scale Systems

The transfer of experience with small-scale irrigation systems also constitutes an attractive possibility for donor support (though one is already receiving attention within Europe). USAID has been closely involved with small-scale systems in several Asian countries (notably Sri Lanka, Indonesia and the Phillipines). It seems likely that the lessons from such experiences may also apply within parts of Africa. The theoretical arguments in favor of small-scale systems have already been reviewed, but still it would be useful to determine to what extent these can be realized in actual practice.

Issues which might be examined under AID funding include:

1. Factors related to the survival of some traditional systems and technologies;

2. Existing institutions for water allocation, maintenance, dispute resolution and cost recovery;

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[1] Perhaps the FAO office working on this topic or the two African REDSO units could provide an organizational base, to which researchers might be attached under a rotating post-doctoral fellowship.

3. Types of perimeter organization already in use;

4. Kinds of technical "backstopping" required in small-scale scale systems;

5. The choice and support of pumps in African environments;

6. Impact of the spontaneous spread of small pump systems; and

7. Options for providing external aid to small-scale systems.

8. NGOs and the Private Sector

Another option for AID support would be to concentrate on helping the NGOs and the PVOs active in African small-scale irrigation. For example, Kenya's small, PVO-assisted schemes reviewed by Kortenhorst (1983) have experienced many technical problems. (Weber's background paper for this study cites numerous examples from other parts of Africa.) These suggest that small schemes can be just as problematic as large ones if designs are faulty or technologies inappropriate. Given that PVO staff are usually motivated and willing to experiment, helping them resolve technological and organizational problems might give AID access to a wide spectrum of African field experiences at comparatively low cost. There are individuals who have accumulated an in-depth understanding of particular aspects of irrigation development, but one usually finds they focus on only one or two elements of the larger process, and they are not free to advise beyond their own limited circle of projects. Outside assistance could help in pooling this valuable experience and making it more widely available.

In regards to private sector irrigation within African countries, there is an equivalent need to stimulate sharing of technological experience between large-scale, commercial operators and PVOs or public agencies working with smallholder farmers.

9. Deepening of US Capacity

The eagerness of US institutions for federal funds sometimes disguises the true situation vis-a-vis availability of manpower and resources to undertake requested technical tasks. This seems to be the case in regard to African development. While there are many American specialists with African experience, most are social scientists without in-depth understanding of the technical side of irrigation. Others lack the French or Arabic or Portuguese needed to undertake field assignments. And still others will find the deteriorating security and supply situation daunting. For all three reasons, we have identified the thinness of US capacity as a major constraint limiting AID's scope of action in the short run.

Remedial interventions should address both staffing and institutional resources. On the staffing side, we have suggested more use of "tag-along" assignments to bring in young professionals who will acquire broadened field experience. This is particularly necessary in regard to the technical specialties (agronomy, irrigation engineering, hydrology, soil science, etc.) but it also applies to irrigation economics and settlement organization. (French and Arabic capability are also crucially important in certain countries, but many potential candidates already have the necessary languages from their initial field assignments.)

In regard to institutional resources, we propose greater use by Americans of London's ODI irrigation network rather than attempting to duplicate this listing of field practitioners. Close liaison with the International Irrigation Management Institute's (IIMI) program for Africa should also be established. Access to field reports and theses on African needs to be improved at the major US institutions which AID intends to involve. Many of the needed resources do exist within the US, but are scattered within institutions which do not have an irrigation emphasis.

Bridging the Gap

This study has aimed to fill a gap in the literature by providing a continent-wide overview of African irrigation experience to date. Our contributors discovered the task sometimes exceeded the means within their reach. Not only is there a major gap between academic sources--which generally can be located within the USA--and the many user-commissioned project reports filed away overseas, there is also a chasm separating engineers who design and construct Africa's schemes from the agronomists and administrators who try to make them work. The first gap was expected, but the second one was not. We close this study, then, by identifying several areas where at present effective inter-communication often breaks down:

- Between civil engineers and agronomists (design versus operation);
- Between scheme managers and farmers;
- Between technology suppliers and technology users;
- Between plot-holders and field workers; and
- Between scheme members and surrounding communities.

The WMS II project originated because of concern that field programs would benefit from an integrated perspective, utilizing water management as a unifying device to highlight interconnections between sectors (and hence, between analytic disciplines). The "synthesis" element expressed AID's belief that field projects should not keep repeating each other's mistakes. This review makes it abundantly clear that both concerns are especially relevant within African irrigation. Present organizational structures virtually guarantee a fragmented approach to irrigation, leaving each set of actors in a position to blame others for the obvious faults which abound on every side. And, as a consequence, learning from past experience does not occur. We hope the views expressed in this report will constitute a first step towards a comprehensive understanding, enabling all those involved to assume collective responsibility and, eventually, to devise more effective solutions.

BIBLIOGRAPHY

Abbot, V. 1982. "Windpumps bring Water to the Turkana Desert," Waterlines, Vol. 12, No. 2, pp. 6-7.

Abdel-Ati, Hassan A. 1983. Technological Change in Agriculture and Socio-Economic Transformation in Northern Sudan 1900-1980. Ph.D. Thesis, University College Swansea, Wales.

Abdel Rahman, Babikar Abdalla and Homoudi, Amna Beshir, 1985. "The Impact of the Kenana Project on Population Redistribution," pp. 265-271. In, Clarke, John, et al. (eds). Population and Development Projects in Africa. Cambridge, England: Cambridge University Press.

Abelin, Philippe. 1979. "Domaine national et développement au Sénégal," Bulletin de l'IFAN, Vol. 41, Serie B. #3.

Academie Des Sciences D'Outre-Mer. 1978. La recherche française en Afrique tropicale et à Madagascar. Paris: Academie des sciences d'Outre-Mer, 271 pp.

Ackerman, W.C., G.B. White and E.D. Worthington (eds.) 1973. Man Made Lakes: Their Problems and Environmental Effects. Washington, D.C.: American Geophysical Union.

Ackers, G.L. and J.W. Gowing. 1983. "Some cost implications of engineering measures for schistosomiasis control," Irrigation in tropical Africa: Problems and Problem Solving. Workshop 24-25 March 1983 African Studies Centre.

Adam, F.H. et al. 1971. "Irrigation Water Sale in the Non-Public Sector in the Northern Province, Democratic Republic of Sudan," Agricultural Economics Bulletin for Africa Vol. 13, pp. 53-57.

Adam, Farah Hassan. 1966. "Contribution of Land Tenure Structures to Agricultural Development in Sudan Through Incentives, Knowledge and Capital," Research Bulletin No. 5, Sudan: Dept. of Rural Economy, University of Khartoum.

Adams, Adrian. 1977. "The Senegal River Valley: What Kind of Change?" Revue of African Political Economy, No. 10, pp. 35-39.

Adams, Adrian. 1981. "The Senegal River Valley," Heyer, Judith et. al. (eds.) Rural Development in Tropical Africa. New York: St. Martin's Press, pp. 325-353.

Adams, William M. 1983. Downstream Impact of River Control; Sokoto Valley, Nigeria. Ph.D. Dissertation, University of Cambridge, England.

Adams, William M. 1984. "Irrigation as Hazard: Farmers' Responses to the Introduction of Irrigation in Sokoto, Nigeria," pp. 121-130. In, Grove, A.T. and W.M. Adams (eds.), Irrigation in Africa: Problems and Problem Solving. Cambridge, England: African Studies Centre, University of Cambridge.

Adams, William M. 1985. "River Control in West Africa," pp. 177-228. In, Grove, A. T. (ed.) The Niger and its Neighbours. Rotterdam: A. A. Balkema.

Adegboro, C. 1983. The Process of Implementation in a Nigerian Bureaucracy: The Case of the Niger River Basin Development Authority. Ph.D. Thesis, University of Pennsylvania, 217 pp.

Adekolu-John, E.O. 1980. "The Probable Impact of the Proposed Jebba Dam on the Health Aspects of the River Niger Basin in Nigeria," Public Health, vol. 84, no. 4, pp. 235-242.

Adekolu-John, E.O. 1983. "Parasitic Diseases and Man-Made Lakes in Nigeria," Public Health, vol. 97, no. 1, pp. 31-37.

Adeniji, H.A. et al. 1981. "Man-made Lakes," in, J. Symoens, M. Burgis and J. Gaudet (eds.) The Ecology and Utlization of African Inland Waters. Nairobi: UNEP, p. 126.

Africare, Inc. 1982. Revised Tara Hydro-Agricultural Project, Tara, Niger. WAshington, D.C.: Africare.

Afrika-Studiecentrum. 1979. "La réforme agro-foncière dans les pays du Conseil de l'Entente en Afrique de l'Ouest," African Perspectives, Vol. 1. Leiden, Netherlands: Afrika-Studiecentrum.

Agency for International Development, see USAID.

Agouba, Mukhtar I. 1979. Social Change in Rural Sudanese Communities --A Case Study of an Agricultural DevelopmentScheme in the Sudan (Khashm el-Girba). Ph.D. dissertation, University of Khartoum.

Ahmed, Abdelgadir Mohammed and Tiffen, Mary. 1986. Water Management in the Gezira Scheme, Sudan. A Survey of Farmers' Attitudes on two Minor Canals. Report OD 76. Wallingford, England: Hydraulics Research, 29 pp.

AISJ. 1971. Le Droit de la Terre en Afrique (au Sud du Sahara). Paris: Editions G-P Maisonneuves et Larose.

Aitken, J.F. 1983. "Relationships between yield of sugar cane and soil mapping units, and the implications for land classification." Soil Survey and Land Evaluation, vol. 3, no. 1, pp. b1-9.

Ajao, F.A. 1980. Nigeria's Yobe Irrigation Scheme: 1959 to 1978. Ph.D. Thesis, University of Pittsburgh, 189 pp.

Akhtar, R.B. 1979. "Management of Irrigation Projects, Upper Benue River Basin Development Authority, Yola, Nigeria," Sixth National Irrigation Seminar Proceedings, Zaria 1979, Ahmadu Bello University, pp. 249-255.

Alam, M.S. 1984. "Incidence of Brown Planthopper (BPH) and White Fly in Nigeria." IRRI Newsletter, Vol. 9, No. 4, pp. 13-14.

Albrecht, H.R. and G. Vallaeys. 1977. "Research Strategies," pp. 1-5. In Leakey, C.L.A. and J.B. Wills, (eds.), Food Crops of the Lowland Tropics. Oxford: University Press.

Alexandroff, et al., 1975. "L'énergie solaire au service de l'agriculture; pompage de l'eau en zones arides." Planification, Habitat, Informations, No. 80, June 1975, pp. 34-49.

Ali, M.A. 1981. "Soils of the Sudan," pp. 100-116. In, F.H. Beinroth and A. Osman (eds.). Proceedings of the Third International Soil Classification Workshop, .

Allan, J.A. 1976. "The Kufrah Agricultural Schemes," Geographical Journal, Vol. 142, No. 1, pp. 48-56.

Al-Tom, Mahdi Amin. 1974. "The Relative Dryness of the White Nile," Sudan Notes and Records, vol. 55, pp. 161-166.

Alverson, Hoyt. 1984. "The Wisdom of Tradition in the Development of Dry-Land Farming: Botswana," Human Organization, vol. 43, no. 1, pp. 1-8.

Alvim, Paulo de T. and T.T. Kozlowski, (eds.) 1977. Ecophysiology of Tropical Crops. New York: Academic Press.

Amadou, Aboubacar. 1979. Agadez et sa région: contribution de l'étude du Sahel et du Sahara Nigerien. Niamey: Etudes Nigeriennes, No. 44.

Amin, M.A. 1977. "Problems and effects of schistosomiasis in irrigation schemes in the Sudan," pp. 407-412. In, Barton Worthington, E. (ed.). Arid Land Irrigation in Developing Countries. London: Pergamon Press.

Amin, Samir, Mark and Sow and Samba. 1975. La Planification du sous-dévoloppement: critique de l'analyse de projets. Paris: editions Anthropos for IDEP, Dakar, 404 pp.

Anderson, Dennis and Fishwick, Robert. 1985. Fuelwood Consumption and Deforestation in African Countries. A Review. World Bank Staff Working Paper No. 704. Washington, D.C.: The World Bank, 66 pp.

Anderson, E. and J. Dupuis. 1980. Evaluation des problèmes techno-économique de la direction de l'hydraulique/ Ministère du développement rural. Mission du 10 au 24 June 1980, 33 pp. Montrouge: SEMA/Conseil en Direction et Gestation, 33 pp.

Anderson, T.J. 1976. Land Tenure and Agrarian Reform in Africa and the Near East: An Annotated Bibliography. Boston, Massachusetts: G.K. Hall and Co.

Andrae, Gunilla and Bjorn Beckman. 1985. The Wheat Trap. London: Zed Books Ltd. the Scandinavian Institute of African Studies.

Ansell, A. and Upton, M. 1979. Small Scale Water Storage and Irrigation. An Economic Assessment for South West Nigeria. University of Reading Development Study No. 17. Reading, England: University of Reading.

Anthonio, Q.B.O. and M. Ijere. 1973. Uboma Development Project 1964-1972. An Appraisal of a Technical Assistance programme for Rural Development in Nigeria. Shell International Petroleum Co. Ltd., 28 pp.

Appel, H.W. and N.M. Vierhout. 1982. "Irrigated Rice polders in the Delta of the Tana River, Kenya," Polders of the World, Vol. 1. Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, pp. 263-275.

Arao, Leo A. 1986. "Review of Past and Present Irrigation Development," pp. 1-18. In, Coward, E. W., Jr. et al. Watering the Shamba. Ithaca, New York: Cornell University.

Ardayfio-Schandorf, E. 1982. Rural Development Strategies in Northern Ghana. Problems and Prospects for Reaching the Small Farmer. Centre for Development Studies, University College of Swansea, England.

Are, L. A. (ed.). 1975. Socio-Economic Aspects of Rice Cultivation in West Africa. Monrovia: WARDA, 216 pp.

Arfaa, F. 1975. "Studies on Schistosomiasis in Somalia, American Journal of Tropical Medicine and Hygiene, Vol. 24, No. 2, 1975, pp. 280-283.

Argouillon, J. 1974. "Les surfaces potentielles pour le développement de la grande irrigation dans la vallée superieure du Niger," L'Agronomie Tropicale, Vol. 29, No. 5 (Mai), pp. 627-640.

Argoullon, J. 1976. Note relative au programme et aux modalities de transfert a la SONADER (Societe Nationale de Développement Rural de Mauritanie) des études, réalisations et mise en valeur de diverses opération d'aménagements hydro-agricoles. Puteaux: SCET International, 36 pp.

Argoullon, J. 1981. Historique du dévelopment des irrigations dans la Basse-Vallée et le Delta du fleuve Sénégal - incidences economiques - systèmes adoptés, Eleventh Congress on Irrigation and Drainage, Vol. 3. Grenoble: ICID.

Arid Lands Information Center. 1981. Environmental Profile on Rwanda. Washington, D.C.: Office of Forestry, Environment and Natural Resources with U.S. Man and the Biosphere Program, 180 pp.

Armitage, F. B. 1985. Irrigated Forestry in Arid and Semi-Arid Lands: A Synthesis. Ottawa: International Development Research Centre, 160 pp.

Arnon, I. 1981. Modernization of Agriculture in Developing Countries. New York: John Wiley, 565 pp.

Arnould, Eric. 1986. "Rice or Millet: The Role of Sociocultural Factors in the Success of Irrigated Agricluture in Niger," Development Anthropology Network, vol. 4, no. 1, pp. 6-11.

Arrighi de Casanova, J. 1974 Etablissement de projet de réseaux d'irrigation. Paris: Ministere de la Coopération, 77 pp.

Arrighi de Casanova, J. 1961. Etude de financement d'aménagements hydro-agricoles. Niamey: République du Niger, 76 pp.

Arrighi de Casanova. 1980. Périmètre irrigués villageois -Economie de l'eau d'irrigation. SATEC--Juin 1980, 24 pp.

Arrivet, J. 1974. Resultats de riziculture sans aménagement en zone soudienne: L' example de bas-fonds au centre Haute Volta. IRAT, Ouagadougou: Ministère du Plan du développement rural et l'environnement et du Tourisme, 23 pp.

Arundale, H. 1978. Report on Irrigation in Arid Regions of Kenya. Nairobi: UNDP (Project No. KEN/74/018/E/01/12).

Asmon, I. E., Njoroge, P. C. and Wandurwa, B. M. 1984. Evaluation of the Turkana Irrigation Cluster. Development Planning Division Working Paper No. 9. Nairobi: Ministry of Agriculture and Livestock Development, Republic of Kenya.

d'At De Saint Foulc, J. 1983. "Les experiences paysannes du développement des cultures au Haute-Volta." Paper presented for the International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. Universite de Paris I, Paris I, Centre d'Etudes Juridiques Comparatives.

Attiya, H. 1983. "Hydraulique étatique, hydraulique paysanne: l'example des hautes steppes Tunisiennes," Colloque International: Développement Agricole et Participation Paysanne. Un Example: les Politiques de L'eau. Universite de Paris 14-15 October 1983.

Audette T, and M. Grolleand. 1984. Le stockage non étatique des grains dans les pays Saheliens. Paris: OCDE, 250 pp.

Auer, Peter (ed.) 19--. Energy and the Developing Nations. New York: Pergamon Press.

Auffret, Henri, "Etude d'aménagement hydro-agricole de la Tamourt en Naaj-Mauritanie," Informations et Documents (BCEOM), No. 2, 4 eme triemtre, 1975, pp. 1-21.

Auriol, O. 1980. Etude des systèmes de production des paysans pratiquant la culture irriguée dans la cadre de la SAED: Premiers resultats. Dakar, Richard Toll: ISRA-ORSTROM, 100 pp.

Auriol, O. 1981. Notes relatives certain groupements de producteurs de la SAED. Richard Toll: ISRA, 76 pp.

Autorité du Bassin Niger, 1980. Inventaire des données topographiques du basin du fleuve Niger. Paris: Institut Géographique Nationale, 242 pp.

Autorité pour l'aménagement de la région du Sud-Ouest (ARSO). 1976. Barrage de Buyo aménagement de la périphèrie du Lac. Programme des études. Abidjan: ARSO, 47 pp.

Autoserre, St. Vincent de. Reprise des travaux d'hydraulique villageoise et pastorale dans la région de N'Djamena. Mission du 22 February - 16 March 1982 (FAC-FED), Paris: BURGEAP, 22 pp.

AVB, 1972. Koussou, aujourdhui et demain. Abidjan.

Ayed, I.A. and A. Wild. 1983. "The distribution of nitrogen in profiles of Sudan Gezira Vertisols with special reference to fixed ammonium." Egyptian Journal of Soil Science, 23(1):53-61.

Ayoade, J.O. 1983. Introduction to Climatology for the Tropics. New York: John Wiley & Sons Ltd.

Azim Abul-Ata, A. 1977. "The Conversion of Basin Irrigation to Perennial Systems in Egypt," Arid Land Irrigation in Developing Countries (Barton Worthington, E. (ed.)), pp. 99-112.

Ba, Alioune. 1976. Amenagement Hydroagricole et Etude Socio-Economique de la cuvette de Dagana. Ph.D. thesis, University of Dakar.

Baak, B.C.P.H. van (compiler). 1976 onwards. Land and Water Development: Selected Literature, 1976. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Baarspul, J.A. 1971. The Tana Irrigation Scheme: An Integrated Development Project. Neath J Agric Sci, Vol. 19, No. 2, pp. 76-84.

Baba, J.M. 1975. Induced Agricultural Change in the Existing Agricultural System in Kura District and the Projected Impact of the Kano River Irrigation Project. Ph.D. Thesis, Amadou Bello University, Nigeria.

Baba, J.M. 1981. "Large-scale Irrigation Development in Nigeria: the Constraint of Labour," Nigerian Journal of Agricultural Extension Vol 1, no. 1, pp. 44-57.

Bacon, C. 1986. "Management in the Agricultural Sector: The Crucial Skills," Ceres, vol. 19, no. 3, pp. 17-20.

Badiane, Alioune. 1984. "Les Petits Périmètres irriguées: une alternative dans le schéma de développement régionale de la Moyenne Vallée du Fleuve Sénégal?" Warango, No. 7, pp. 14-16.

Bagadion, Benjamin U. and Korten, Frances F. 1985. "Developing Irrigators' Organizations: A Learning Process Approach," pp. 52-90. In, Cernea, M. (ed.) Putting People First. New York: Oxford University Press.

Bah, Boubacar. 1982. La participation dans les projets de cultures irriguées. Bamako: CILSS, Bureau d'études, de Conseils et d'intervention au Sahel, 60 pp.

Bahemuka, Judith. 1983. Socioeconomic Role of Women in Kenya; Bura Irrigation and Settlement Scheme. Ithaca, New York: College of International Agriculture, Cornell University.

Baillargeat, P. Hydrologie du delta du Sénégal (rive droite du fleuve). Grenoble: SOGREAH, 84 pp.

Bailly, Pare. 1980. Participation française au seminaire de formation de techniciens de D.R.S. organisé par le CILSS à Dakar du 15 août au 1er dec. 1979. Paris: Ministère de la Coopération. GERDAT.

Bajsarowicz, J. and J. Welton. 1979. "Surface Water-Groundwater Conditions in the Senegal River Basin near Matam, Senegal, in International Association of Scientific Hydrology," The Hydrology of Areas of Low Precipitation, pp. 235-248.

Baker, Kathleen. 1982. "Structural Change and Managerial Inefficiency in the Development of Rice Cultivation in the Senegal River Region." African Affairs, Vol. 81, No. 325, pp. 499-510.

Baker, P. R. 1970. "The Introduction of Rice in Rwanda," Journal of Tropical Geography, Vol. 31, pp. 27-33.

Baker, R. 1970. The Soils of Tanzania. FAO, Rome. (with maps) (unpublished).

Balbo, Jean-Louis. 1975. "Sahel: Mettre la culture irriguée entre la main des paysans," Actual Développment, No. 6, mars-avril, 1975, pp. 38-45.

Balbo, J.L. "L'experience des petits périmètres au Tchad," périmètres irriguées villageois: Seminaire tenu à Dakar du 21 au 23 avril 1980. Paris: SATEC, pp. 30-37.

Baldensperger. J., J.P. Staimesse, and C. Tobias. 1968. Carte pédologique de moyenne Casamance au 1:200,000. ORSTOM, Dakar-Hann.

Baldwin, Kenneth. 1957. The Niger Agricultural Project: An Experiment in African Development. Cambridge, Mass.: Harvard Univ. Press.

Balek, J. 1977. Hydrology and Water Resources in Tropical Africa. Amsterdam: Elsevier.

Ballantyne, A.O. 1968. Soils of Zambia. Mount Makulu Research Station.

Bangladesh Agricultural Research Council. 1986. Methodologies to Evaluate the Performance of Irrigation Systems. Dhaka: Bangladesh Agricultural Development, 291 pp.

Bannerman, R.R. 1973. "Problems Associated with Development of Groundwater in Igneous and Metamorphic Rocks: a Case Study in Ghana," Groundwater Vol. 11, no. 5, pp. 31-34.

Barber, W. 1965. "Pressure Water in the Chad Formation of Bornu and Dikwa Emirates, Northeastern Nigeria," Geological Survey of Nigeria, Bulletin 35. Nigeria: Ministry of Mines and Power.

Barbour, K. M. 1972. "Irrigation in the Sudan: Its Growth, Distribution and Potential Extension," pp. 121-139. In, Prothero, R. (ed.) People and Land in Africa South of the Sahara. New York: Oxford University Press.

Barclay, A.H., Donald S. Humpal, Chris Dunford, and James Seyler. 1982. Second Annual Review of the Rural Sector Grant. Prepared for USAID/Gabarone and the Government of Botswana Reference Group. Gaborone, Botswana: Development Alternatives, Inc.

Barneaud, J.C. 1977. Exhaure de l'eau, Pompe à bouchous. Paris: IRFED, 25 pp.

Barneaud, J.C. and M.F. Desbryuères. 1978. Rapport de Stage WLI (Région Maritime) Togo. 4 au 25 Août, 1978, Paris: IRFED, 71 pp.

Barnes, A.C. 1974. The Sugar Cane. New York: Halsted Press, John Wiley and Sons.

Barnett, A.S. 1975. "The Gezira Scheme: Production of Cotton and the Reproduction of Underdevelopment," Oxaal, I. et al (eds.), Beyond the Sociology of Development pp. 183-207. London: Routledge & Kegan Paul.

Barnett, Tony. 1977. The Gezira Scheme: An Illusion of Development. London: Frank Cass, 192 pp.

Barnett, Tony. 1979. "Why are Bureaucrats Slow Adopters? The Case of Water Management in the Gezira Scheme," Sociologia Ruralis, Vol. 19, no. 1.

Barnett, Tony. 1981. "Evaluating the Gezira Scheme: Black Box or Pandora's Box?" pp. 306-324. In, Heyer, Judith, et al. (eds.) Rural Development in Tropical Africa. New York: St. Martin's Press.

Barnett, Tony. 1982. Notes for Meeting on Small Scale Irrigation in Africa. Rome: FAO. November 1982.

Barnett, Tony. 1984. "Small-Scale Irrigation in Sub-Saharan Africa: Sparse Lessons, Big Problems, Any Solutions?" Public Administration and Development, vol. 4, pp. 21-47.

Barrett, E.C. and D.W. Martin. 1981. The Use of Satellite Data in Rainfall Monitoring. London: Academic Press.

Barry, R.G. and R.J. Chorley. 1976. Atmosphere, Weather and Climate. London: Methuen & Co. Ltd.

Bates, Robert H. 1981. Markets and States in Tropical Africa. Berkeley: University of California Press, 178 pp.

Battut, P. and H. Serres. 1974. Rapport sur l'étude des possibilitiès de développement intègre dans le périmètre de Baguinedà. Paris: Ministère de la Coopération, 93 pp.

Baudoin, et. al. 1976. Compterendus de quelques essais d'irrigation au goutte à goutte. Dakar: Ministère de dévelopement rural, 75 pp.

Baum, A. 1983. "Socio-Economic Observations on Tenants' Reactions in National Irrigation Board (NIB) Schemes in the Kano Plains, Kenya," DVWK Bulletin 8. Hamburg/ Berlin: Verlag Paul Parey, pp. 71-84.

Baum, G.A., Migot-Adholla, S. 1982. "South Kano Irrigation Scheme--Socio-Economic Adjustments in Rural Development Planning," Quarterly Journal of International Agriculture, Vol. 21, No. 1, Jan-Mar, pp. 37-51.

Bawden, M.G. and A.R. Stobbs. 1963. The land resources of eastern Bechuanaland. Tolworth, Surrey, U.K: Directorate of Overseas Surveys, Forestry and Land Use Section.

Bawden, M.G. 1965. Some Soils of Northern Bechuanaland. Tolworth, Surrey, U.K.: Directorate of Overseas Surveys, Land Resources Division.

Bawden, M.G. and D.M. Carroll. 1968. The Lands Resources of Lesotho. Tolworth, Surrey, U.K.: Land Resources Division, Directorate of Overseas Surveys, (with 2 map sheets at 1:250,000).

BBC. 1984. Talk narrated to Michael Pickstock, from John Bell. Drip Irrigation for Sugar Cane in Mauritius. The Farming World - 1292 - Week 3 - Talk List 16.1.84. (on tape). British Broadcasting Corporation, London.

BDPA. 1969-1972. Opération Maraîchage Kinshasa, 4 Vol. Paris: BDPA.

BDPA/Bureau de génie rural. 1976. Ceinture verte de Kinshasa. Paris: BDPA.

Beadle, L.C. 1974. The Inland Lakes of Tropical Africa: an Introduction to Tropical Limnology. London: Longman.

Beckman, Bjorn. 1986. "Bakolori: Peasants versus State and Industry in Nigeria," pp. 140-155. In, Goldsmith, E. and Hildyard, N. (eds.) The Social and Environmental Effects of Large Dams, vol. 2, Case Studies. Camelford, Cornwall: Wadebridge Ecological Centre.

Beer, C.W. 1955. "Social Development in the Gezira Scheme," African Affairs, vol. 54, no. 214, pp. 42-51.

Beer, L.W. 1953. "The Social and Administrative Effects of Large-Scale Planned Agricultural Development," Journal of African Administration, vol. 5, no. 3, pp. 112-119.

Behnke, Roy. 1985. "Measuring the Benefits of Subsistence versus Commercial Livestock Production in Africa," Agricultural Systems, vol. 16, pp. 109-135.

Bell, A.A. 1984. "Cotton Protection Practices in the USA and the World. Section B: Diseases," pp. 289-306. In: Kohel, R.J. and C.F. Lewis, (eds.) Cotton. Agronomy Mongraph No. 24. Madison, Wisconsin: American Society of Agronomy.

Bellander, M. (n.d.) Coordination en matière d'hydraulique au Tchad. Paris: Secretariat d'etat aux affaires étrangères.

Belloncle, Guy. 1971. "Une Expérience d'animation Coopérative au Niger," pp. 207-227. In, Desroches, Henri, and Placide Rambaud (eds.), Villages en Développement: Contributions à une Sociologie Villageoise: Actes des premier et deuxième colloques d'Albiez-le-Vieux. Paris: Mouton, pp. 201-227.

Belloncle, Guy. 1973. Les Coopératives dans le Cadre du Projet de Developpement Rural de Maradi. Paris: IRAM, 24 pp.

Belloncle, Guy. 1981. Structures villageoises et stratégies de développement projets educatife en Afrique Noire. Paris: Bureau d'Etudes Coopératives et Communautaires.

Belloncle, Guy. 1982. Alphabetisation et gestion de groupements villageois en Afrique Sahelienne. Paris: Club/Ouagadougou/CILLS, 270 pp.

Belloncle, Guy. 1982. "Les Associations Villageoises," pp. 75-84. In, La Question Paysanne en Afrique Noir. Paris: Editions Karthala.

Belloncle, Guy. 1982. Propositions pour la mise-en-place de systèmes de compatabilitè et de gestion maitrisable par les périmètres irrigués encadres par SAED. Rapport de mission effectuée du 21 mai au 5 juin 1982. Dakar: SAED.

Belloncle, Guy. 1984. "Des systèmes de gestion simplifiés elaborés dans les langues maternelles des paysans comme préalables absolus à toute participation des populations à la gestion des aménagements hydro-agricoles," Développement Agricole et Participation Paysanne. Un exemple, la Politique de l'eau en Afrique. Paris: CNRS-CEJC.

Belloncle, Guy. 1984. "Giving Management Skills to Farmer's Groups," pp. 2-7, In. "Farmer's Associations--Making Them Effective or Making Them Unnecessary," Irrigation Management Network Paper 9c. London: Overseas Development Institute.

Bellot, C.B., 1976. L'aménagement des vallées des Voltas et l'example de Kaibo. Grenoble: Université Scientifique et Médical de Grenoble, Institut de Géographie Alpine.

Bellot, J.M. 1977. Potentialités pour un aménagement du cours moyen de la Volta Noire et de la Vallée de Sourou. Grenoble: Université Scientifique et Médical de Grenoble.

Bellot-Couderec, Beatrice and Jean-Marc Bellot. 1978. "Pour un aménagement du cours moyens de la Volta Noire et de la vallée du Sourou," Les Cahier d'Outre Mer, No. 123, July-September 1978, pp. 271-286.

Belorgey/Ruche/Madec. 1975. Rapport de mission concernant "le projet de mise en valeur des polders du lac Tchad." Paris: Ministère de la Coopération, 7 pp.

Benedict, Peter, et al. 1982. Sudan: the Rahad Irrigation Project, Aid Impact Evaluation Report No. 31. Washington, D.C.: USAID.

Benedil, P. 1977. Note Methologique; Evaluation Economique et Foncière des Projets Périmètres d'irrigation Villageois. Paris: SATEC, 44 pp.

Berg, Elliott. 1975. The Recent Economic Evolution of the Sahel. Ann Arbor, Michigan: Center for Research on Economic Development, Univ. of Michigan, 247 pp.

Berg, Elliott. 1980. "Reforming Grain Marketing Systems in West Africa: A Case Study of Mali," pp. 147-172. In, ICRISAT, Proceedings of the International Workshop on Socio-economic Constraints to Development of Semi-Arid Tropical Agriculture, Pantacheru, India: ICRISAT.

Berg, Gerald M. 1981. "Riziculture and the Founding of the Monarchy in Imerina". Journal of African History. Vol. 22, no. 3, pp. 289-308.

Berger, A.R. (ed.). 1975. Geoscientists and the Third World: a Collective Critique of Existing Aid Programmes. Ottawa: Geological Survey of Canada.

Bergmann, Helmuth et J.M. Boussard, 1976. Guide de l'élevation Economique des Projets d'irrigation. Paris: OCDE, 261 pp.

Bernengo, O. 1983. Contribution de la reflexion de la SAED sur les possibilités de desengagement des opérations de maintenance des GMP sur le projet Matam. Rapport de mission du 5 au 25 Janvier. Paris: Ministère de la la Coopération. St. Louis: FAC/SAED, 20 pp.

Bernus, Edmond. 1970. "Les Palmeraies de l'Aii," Revue de l'Occident Musulman et de la Mediterranée, Vol. II, pp. 37-50.

Bernus, Edmond. 1974. "L'évolution récente des relations entre éleveurs et agriculteurs en Afrique tropicale. L'exemple du Sahel Nigérien," Cahiers de l'ORSTOM, Série Sciences Humaines, Vol. 11, No. 2, pp. 137-143.

Bernus, Edmond. 1974. "Possibilitiés et limites de la politique d'hydraulique pastorale dans le sahel nigerien," Cahiers de l'ORSTOM, Série Sciences Humaines, Vol. 11, No. 2, pp. 119-126.

Bernus, Edmond. 1977. "Les Eleveurs face à la Sécheresse en Afrique Sahelienne: Exemples Nigériens." In, Dalby, David et al. (eds.) Drought in Africa. African Environment Special Report, No. 6. London: International African Institute.

Berry, L. and R.W. Kates. 1970. "Planned Irrigation Settlement. A Study of Four Villages in Dodom and Singida Regions, Tanzania." BRALUP Research Paper, No. 10. Dar es Salam: BRALUP, University of Dav es Salaam, 63 pp.

Berry, Leonard, Richard Ford and Richard Hosier. 1980. The Impact of Irrigation on Development: Issues for a Comprehensive Evaluation Study. AID Program evaluation discussion Paper No. 9. Washington, D.C.: USAID, 70 pp.

Beshah, T.W., J.W. Herbeson. 1978. "Afar Pastoralists in Transition and the Ethiopian Revolution," Journal of African Studies, Vol. 5, No. 3, pp. 249-267.

Bessis, Sophie. 1982. "Recalculating River Development Costs," Ceres Vol. 15, no. 5, pp. 21-26.

Bessis, Sophie. 1981. "Faut-il Construire les Barrages sur le Sénégal?" Jeune Afrique, 22 juillet, pp. 53-56.

Betbeder-Matibet, M. 1981. "Eldana Saccharina Walker, Foreur des Tiges de la Canne à Sucre en Afrique," Agronomie Tropicale, Vol. 36, No. 3, pp. 279-293.

Beudot, Françoise. 1977-83. Elements de Bibliographie sur la sécheresse au Sahel. Updating Nos. 1-7. Paris: OCDE.

Beunard, P. and J. Pichot. 1981. "Fixation de l'Azote dans la Rhizosphère de Six Variétés de Riz: Etude en Milieu Contrôlésur un Sol Ferrugineux Tropical du Sénégal." Agronomie Tropicale, Vol, 36, No. 3, pp. 212-216.

Beyard, N. 1977. "L'aménagement des Vallées des Voltas," Afrique Agriculture, No. 25, Septembre, pp. 32-41.

Beye, Gora. 1975. "Bilan de cinq années d'études du dessalement des sols du polder de Medine (Basse Casamance), Sénégal," Agronomie Tropicale, Vol. 30, No. 3, pp. 251-263.

Beyer, J.L. 1980. "Africa," pp. 5-38. In, Klee, G. A. (ed.), World Systems of Traditional Resource Management London: Edward Arnold.

BGB International Consultants. 1969. 1) "Management Study of the Surrounding Region of Kossou Lake - Terms of Reference." 2) "Demarcation of the Study Zone (Kossou)."

Bichet, Martin. 1976. Collecte, stockage, utilisation des eaux pluviales dans les pays du Sahel. Utilisation des techniques au niveau du village. Bibliographie selec-tive et analytique. Paris: IRFED, 99 pp.

Bichat, H. 1976. "L'aménagement des Petits Bas-fonds à Vocation Agricole," L'Enfant en Milieu Tropicale, No. 103, pp. 32-36.

Bidaux, J.M. 1971. "La Riziculture en eau Profonde au Mali," L'Agronomie Tropicale, Vol. 26, pp. 1100-1114.

Biebiuck, Daniel (ed.). 1963. African Agrarian Systems. London: International African Institute, Oxford University Press.

Bigot, Jean. 1971. L'exécution des irrigations à la raie au moyen des siphons tubulaires. Robot: Ministère de l'Agriculture, 22 pp.

Bingen, R.J. 1983. The Role of the State in Food Production and Rural Development: Lessons from Opération Riz-Ségou in Mali (Sahel). Ph.D. Thesis, University of California, Los Angeles. 350 pp.

Bingen, R. James. 1985. Food Production and Rural Development in the Sahel. Lessons from Mali's Operation Riz-Segou. Boulder, Colorado: Westview Press, 167 pp.

Bird, Alan. 1985. "La participation des paysans dans l'élaboration et la mise en oeuvre des grands projets de mobilisation des ressources en eau du Nigéria, Comparaison du projet d'irrigation de Bakolori et du projet de réaménagement de Dadin Kowa," pp. 550-556. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Developpement agricole et participation paysanne. Paris: Economica.

Bird, A. 1984. "The Land Issue in Large Scale Irrigation Projects: Some Problems from Northern Nigeria," pp. 75-85. In, Grove, A.T. and W.M. Adams (eds.), Irrigation in Africa: Problems and Problem Solving. Cambridge, England: African Studies Centre, University of Cambridge.

Bird, Alan. 1983. "Farmer Participation in the Planning and Implementation of Nigerian Large Scale Water Resources Schemes. Bakolori Irrigation Project and Dadin Kowa Resettlement Project Compared." Paper presented for the International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. University of Paris I, Centre d' Etudes Juridiques Comparatives.

Birke, L. 1970. The Impact of the Dogali Irrigation Project on the National Income of Ethiopia. Ph.D. Thesis, Ohio State University, 131 pp.

Biscaldi, R. 1974. L'équipement hydraulique du Sahel. Paris, pp. 53-56.

Biswas, A. K. 1985. "Methodology for Monitoring and Evalution of Integrated Land and Water Development," pp. 49-61. In, Lundqvist, Jan, et al. (eds.) Strategies for River Basin Management. Dordrecht, the Netherlands: D. Reidel.

Biswas, Asit K. 1986. "Irrigation in Africa," Land Use Policy, Vol. 3, No. 4, pp. 269-285.

Blackie, M.J. (ed). 1984. African Regional Symposium on Small Holder Irrigation, (5-7 September, Harare, Zimbabwe). Wallingford, England: Hydraulics Research Ltd. jointly with University of Zimbabwe, Harare, Zimbabwe under sponsorship of the British Overseas Development Administration, 437 pp.

Blackie, Malcom J., Hungwe, Alois and Rukuni, Mandivamba (1984) Irrigation Development and Water Management Strategies in Kenya and Zimbabwe. Nairobi: Eastern and Southern Africa Office, Ford Foundation, 92 pp.

Blanc-Pamard, Chantal. 1985. "Communautés Rurales des hautes terres Malgaches et gestion de l'eau," pp. 421-442. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Développement agricole et participation paysanne, Paris: Economica.

Blench, Roger. 1987. "Livestock in the Gezira Scheme," Pastoral Development Network Paper No. 23c. London: Overseas Development Institute.

Bloch, Peter, et al. 1986. "Senegal: Sengegal River Basin," pp. 29-41. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, University of Wisconsin-Madison.

Bocquier, G., R. Boulet and M. Gavaud. 1964. Carte pédologique de reconnaissance de la République du Niger: Niamey, Maradi, Zinder au 1:500,000. ORSTOM, Dakar-Hann. (3 sheets.)

Boer, P.G. de., 1975. "Present Situation and Future Plans for Rice Production in West Africa," pp. 49-54. In, Report on the Expert Consultation Meeting on the Mechanization of Rice Production. Ibadan: International Institute for Tropical Agriculture.

Bolton, Peter. 1986. "Mozambique's Cabora Bassa Project: An Environmental Assessment," pp. 156-167. In, Goldsmith, E. and Hildyard, N. (eds.) The Social and Environmental Effects of Large Dams, vol. 2, Case Studies. Camelford, Cornwall: Wadebridge Ecological Centre.

Bolton, P. 1987. "Schistosomiasis: Engineering Controls," ODU Bulletin, Hydraulics Research, Wallingford, July (no. 7), pp. 4-17.

Bonnefond, Robert and Jacques Mayer. 1973. Les Riziculture Paysannes, Ameliorations Possibles. Paris: SEAE.

Bonnefond, Philippe and O. Auriol. 1980. Etude des Systèmes de Production des Paysans Pratiquant la Culture Irriguée dans le cadre de la SAED, Premiers Resultats. Richard Toll, Dakar: ISRA/ORSTON, 100 pp.

Bonnefond, Philippe and J. Caneill. 1981. Systémes des Cultures Irriguée et Unités de Production Paysanne sur la Rive Gauche de Fleuve Sénégal, Etudes Scientifiques. Dakar: ORSTOM, 44 pp.

Bonnefond, Philippe, et al. 1981. Etudes d'unités de Paysans Pratiquant la Culture Irriguée dans le Cadre de la SAED. Richard Toll, Dakar/Paris: ISRA/ORSTOM/IRAT/INA/PG.

Bonnefond, Philippe. 1982. "L'introduction de la culture irriguée sur les rives Sénégalaises du bassin du fleuve Senegal," Economie Rural, pp. 147-148.

Bonnemaison, J. 1970. "Des Riziculteurs d'Altitude Tsarahonenana, Village de l'Ankaratra (Madagascar)," Etudes Rurales Nos. 37-38-39, pp. 326-345.

Bonz:, S.M. 1982. "Chilo diffusilineus l. de Joannis (Lepidoptere pyralidae) borer des tiges de cereales en cultures irriguées et pluviales en Haute Volta (Burkina Faso)," Agronomie Tropicale, Vol. 37, No. 2, pp. 207-209.

Boodhoo, M.J. and C. Fuller. 1981. "Irrigated Settlement--An Appraisal of the Ahero Pilot Irrigation Scheme in Kenya," Manchester Papers on Development Vol. 1., No. 1, pp. 73-114.

Booher. 1974. L'irrigation de surface. Rome: F.A.O., 148 pp.

Borden, R.W. 1984. "Soil Survey for Irrigation Projects: A Discussion of Typical Problems," pp. 20-26. In, Adams, W. M. and Grove, A. T. (eds.) Irrigation in Tropical Africa. Cambridge African Monographs, No. 3. Cambridge, England: African Studies Centre, Cambridge University.

Bornemisza, Elemer and Alvarado, Alfredo (eds.) 1975. Soil Management in Tropical America. Raleigh, N.C.: Soil Science Dept., North Carolina State University for the University Consortium on Soils of the Tropics, 565 pp.

Botswana Society. 1976. Proceedings of the Symposium on the Okovango Delta and its Future Utilisation. (August 30 - September 2). Gaberone, Botswana: Bostwana Society.

Bottrall, Anthony. 1978. "The Management and Operation of Irrigation Schemes in Less Developed Countries," pp. 309-322. Widstrand, Carl (ed.), The Social and Ecological Effects of Water Development in Developing Countries. New York: Pergamon Press.

Bottrall, Anthony F. 1981. Comparative Study of the Management and Organization of Irrigation Projects. World Bank Staff Working Paper No. 458. Washington, D. C.: The World Bank.

Bottrall, Anthony. 1985. Managing Large Irrigation Schemes: a Problem of Political Economy. Agricultural Administration Unit, Occasional Paper 5. London: Overseas Development Institute, 81 pp.

Bouchard, L. and M. Damour. 1976. "Exigences Edaphiques du Tabac en Culture de Décrue sur Sols alluviaux de Centre-Ouest et du Nord-Ouest de Madagascar," Agronomie Tropicaī, Vol,. 31, No. 3, pp. 232-244.

Boudet, Gabriel. 1970. Etudes en vue de la mise en valeur du dallol Maouri, Niger. Rome: FAO/UNDP Rapports Techniques, 308 pp.

Boudet, Gabriel. Manuel sur les paturages tropicaux et les cultures fourragères. Vol. 4. Paris: SEAE (IEMVT), 258 pp.

Boulchi-Lamontagne Michel. 1983. "Les sourciers du Sahel,"Actuel Développements, No. 53, March 1983, pp. 29-31.

Boulet, R. 1968. Etude Pedologique de la Haute-Volta, Regional Centre-Nord. ORSTOM, Dakar-Hann. (with map at 1:500,000).

Boulet, R. and J. Vieillefon. No date. Carte Provisoire de Mauritanie au 1:5,000,000. (Unpublished).

Boumendil, H. 1982. Dossier d'appel d'offres pour l'études d'aménagement de sept cuvettes du fleuve Niger. Paris: IRAM, 53 pp.

Bouqet, Christian. 1969. "La culture de blé dans les polders du lac Tchad," Les Cahiers d'Outre Mer, No. 86, Avril-Juin, pp. 203-214.

Bouqet, Christian. "L'homme et les plaines alluviales en milieu tropicale. Iles et rives du sud-Kanem (Tchad). Etude de géographie régionale," Travaux et documents de géographie tropicale. No. 13. Bordeaux: Centre d'etudes de geographie tropicale, Université de Bordeaux.

Bouquet, Christian. 1983. "La maitrise de l'eau dans les wadi et polders de Lac Tchad." Colloque Internationales: Développement agricole et participation paysanne, un example: les politiques de l'eau. Paris: CNRS-CEJC, 14-15 October, 1983.

Bourdel, Christian. 1976. Essais d'évaluation des consequences d'une opération d'irrigation en pays de la Zone Sahelienne Sèche. Paris: Ministère de l'agriculture.

Bourdel, Christian. 1976. Essais d'évaluation des consequences d'une opération d'irrigation en Pays de la zone Sahelienne sèche. Paris: Ministère de l'agriculture, 129 pp.

Bourdel, Christian. 1976. Essais d'évaluation des consequences d'une opération d'irrigation en pays de la zone sahelienne sèche, exemple Ibohamane au Niger. Ecole Nationale du Genie Rural des Eaux et des Forets, Paris.

Bourgeat, F. No date. Notices sur les cartes pedologiques de reconnaissance (Anbsohiby au 1:200,000). Tananarive: ORSTOM.

Bourgeois, M. 1978. Carte de planification des ressources en eau Côte d'Ivoire, Ghana, Toga, Benin. Paris: (IEM) FAC.

Bourricaud, François. 1959. Aménagements hydro-agricole de la Vallée du Sourou: Conclusions générales. Bordeaux: Institut des Sciences Humaines Appliquées.

Boutillier, J.L. 1962. La moyenne vallée du Senegal. Paris: Ministère de la Coopération, 368 pp.

Boutillier, J.L. 1980. "Irrigated Farming in the Sénégal River Valley," Workshop on Sahelian Agriculture, May 1980. Lafayette, Indiana: Department of Agricultural Economics, Purdue University.

Bowden, M.J., et al. 1981. "The Effect of Climate Fluctuations on Human Populations: Two Hypotheses," pp. 479-514. In, Wigley, T., et al. Climate and History. Cambridge, England: Cambridge University Press.

Bower, Blair T. and Hufschmidt, Maynard M. 1984. "A Conceptual Framework for Analysis of Water Resources Management in Asia," Natural Resources Forum, vol. 8, no. 4, pp. 343-355.

Boyer, Jean. 1970. "La fertilité des sols en Afrique intertropicale francophone." Afrique contemporaine No. 5, Sept-Oct 1970, pp. 2-10. Université de Paris I, Centre d'Etudes Juridiques Comparatives.

Bradley, P., Raynaut, C. and Torrealba, J. 1977. The Guidimaka Region of Mauritania. London: War on Want, 173 pp.

Brainard, J.M. 1981. Herders to Farmers: The Effects of Settlement on the Demography of Turkana Population of Kenya, Ph.D. Thesis, State University of New York at Binghamton, 356 pp.

Breman, H. and C.T. de Wit. 1983. Rangeland productivity and exploitation in the Sahel. Fifth conference of the Club du Sahel, Brussels, 26-28 October 1983. Paris: Club du Sahel/ CILSS, OCED.

Bremond, Reve. 1961. Problèmes pratiques et d'organisation en matière, de construction de puits d'eau en grand diamètre. Paris: Comité Inter-Etats d'Etudes Hydrauliques, 12 pp.

Bremond, Reve. 1965. Construction des puits de captage d'eau. Paris: Gauthier-Villars, 82 pp.

Brenière, J. 1976. "Etudes et Travaux - Reconnaissance des Principaux Lepidopteres du Riz de l'Afrique de l'Ouest." Agronomie Tropicale, Vol. 31, No. 3, pp. 213 à 231.

Brenière, J. 1981. "La lutte intègre contre les ravageurs des cultures vivrières tropicales," Agronomie Tropicale, Vol. 36, No. 1, pp. 78-81.

Brenière, J. and D. Bordat. 1982. "Intérêt et difficultiés de la lutte biologique par introduction d'entomophages--cas des foreurs du riz en Afrique," Agronomie Tropicale, Vol. 37, No. 2, pp. 203-206.

Brera, A. and Shahrokhi, F. 1978. Application of Landsat Data to Monitor Desert Spreading in the Sahara Region." In, Shahrokhi, F. (ed.) Remote Sensing of Earth Resources, vol. 3. Tullahoma, Tennessee: Univ. of Tenn. Space Institute.

Breuer, A. and A. Netzband. 1979. Irrigation de petite unité. Eschborn: German Appropriate Technology Exchange, 102 pp.

Bridges, E.M. 1970. World Soils. Cambridge: University Press.

BRGM. 1982. L'hydraulique villageois dans les pays - membres du CILLS - situation au Niger. Enquête et propositions en vue d'une gestion rationelle de l'eau. Rapport du projet d'appui aux Directions de l'Hydraulique. Paris: CILLS/Club du Sahel, 85 pp.

Briggs, J. 1983. "Farmers' Management of Small-Scale Irrigation Schemes in Central Sudan." Paper presented for the International Conference: Developpement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Briggs, J. 1986. "The Background to the Gummuiya Scheme." pp. 115-119, In, Davies, H.R.J. (ed.) Rural Development in White Nile Province, Sudan. Toyko, United Nations University.

Briggs, J. 1986. "The Gummuiya Development Scheme," pp. 120-128. In, Davies, H.R.J. (ed.) Rural Development in White Nile Province, Sudan. Tokyo: United Nations University.

Brinkerhoff, Derick W. 1980. "Realities in Implementing Decentralization, Coordination, and Partipation: The Case of the Mali Rural Health Project." Development Discussion Paper No. 105. Cambridge, MA: Harvard Institute for International Development, Harvard University, 40 pp.

Broche-Due, Vigdis and Storas, F. 1983. The Fields of the Foe--Factors Constraining Agricultural Output and Farmers' Capacity for Participation on Katilu Irrigation Scheme. Bergen: University of Bergen/NORAD.

Broche-Due, Vigdis. 1983. "Women at the Backstage of Development--The Negative Impact on Project Realization by Neglecting the Crucial Roles of Turkana Women." Rome: FAO.

Brokensha, D. M., M. Horowitz and T. Scudder. 1977. The Anthropology of Rural Development in the Sahel: Proposals for Research. Binghampton, N.Y.: Institute for Development Anthropology.

Brokensha, D.W. and T. Scudder. 1968. "Resettlement," Rubin, N. and W. M. Warren (eds.) Dams in Africa London: Frank Cass.

Brokensha, D.W., D.M. Warren and O. Werner (eds.) 1980. In., Indigenous Knowledge Systems and Development Systems and Development. Landau, MD: University Press of America.

Bromley, D.W. 1982. Improving Irrigated Agriculture: Institutional Reform and the Small Farmer. World Bank Staff Working Papers, No. 531. Washington, D.C.: The World Bank, 80 pp.

Brondolo, John D. 1985. Irrigated Agriculture in the Sahel: the Donor Experience (A Review of 15 Irrigated Projects), Cambridge, MA: John F. Kennedy School of Public Administration, Harvard University for AID (Office of the Sahel and West Africa), 38 pp.

Brouwer, R. 1982. "Hadejia Valley Irrigation and Drainage Project, Nigeria," Polders of the World, Vol. 1, Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, pp. 255-263.

Brown, D.S. and C.A. Wright. 1985. "Schistosomiasis: Bilharzia," pp. 295-317. In, Grove, A.T. (ed.) The Niger and its Neighbours. Rotterdam: A. A. Balkema.

Brown, L. 1971. East African Mountains and Lakes. Nairobi: East African Publishing House.

Brown, Elizabeth, J. 1980. Irrigation in Arid Zones - Kenya, A Socio-Anthropological Survey of the Irrigation Schemes on the Turkwell River. AG: DP/KEN/78/015, con-sultant report, FAO, Rome.

Brown, P. and A. Young. 1966. The Physical Environment of Central Malawi with Special Reference to Soils and Agriculture. (with soil map at 1:1,250,000.)

Brunt, M. 1959. Land Use Map of the Gambia. Directorate of Overseas Surveys. (12 sheets at 1:25,000.)

Buchanan, Susan. 1983. "Trip Report for 19 November to 17 January" dated 11 February (unpublished memo). USAID/Mali.

Buchmann, E. 1983. "Les aménagement hydro-agricoles de la SEMRY au Nord Cameroun: contributions à une meilleure perception des facteurs du succés et d'evolution Favorable des Grands Aménagements." Paper presented for the International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Buddenhagen, I.W. and G.J. Persley. 1978. Rice in Africa: Proceedings of a Conference held at the Institute of Tropical Agriculture, Ibadan, Nigeria, 7-11 March 1977. New York: Academic Press.

Buddenhagen, I.W. and G.J. Persley (eds.). 1979. Rice Development Strategies in Africa. London: Academic Press.

Buddenhagen, I.W. 1983. Plant Breeding or Pesticides to Narrow the Field Gap? A paper presented at the 10th International Congress on Plant Protection, Brighton, England.

Buignicourt, James. 1976. Senegal River Valley: A Threatened Environment and Landscape. Dakar: ENDA, 28 pp.

BEDI. 1978. Etude économique en vue du projet de petits barrages dans la région des Mont Mandara (Margui-Wamdalu), Cameroun. Yaoundé: BEDI, 90 pp.

Buol, S.W. et al. 1980. Soil Genesis and Classification. Ames, Iowa: Iowa State University Press, 404 pp.

Burchi, Stefano. 1984. "Legal and Institutional Aspects of the Equitable Sharing in the Water Resources of Four River Basins Common to Nigeria and Niger." Report to the Nigeria-Niger Joint Commission for Cooperation. Rome: FAO.

BURGEAP. 1980. La construction des puits en Afrique. Collections Techniques rurales en Afrique. Paris: Ministée de la Coopération, 200 pp.

Burnet-Jailly, J. 1981. "L'introduction de la riziculture irriguée en pays Mousgoum," Révue de Géographique du Cameroun, Vol. 2, No. 2, pp. 77-96.

Burnham, P. 1980. "Changing Agricultural and Pastoral Ecologies in the West African Savanna Region," Harris, B. R. (ed.) Human Ecology in Savanna Environments. London: Academic Press, pp. 147-170.

Butcher, D.A.P. 1971. An Operational Manual on Resettlement. FAO, Rome.

Butler, B.E. 1980. Soil Classification for Soil Survey. Oxford: Clarendon Press, 129 pp.

Butzer, K.W. 1971. Recent History of an Ethiopian Delta. University of Chicago Department of Geography Research, Paper 136. Chicago: University of Chicago.

Buursink, J. 1971. Soils of Central Sudan. Utrecht: Schotanus and Jens.

Byerlee, D. and J. Longmire. 1986. "Wheat in the Tropics: Whether and When," Ceres. vol. 19, no. 3, pp. 34-39.

Cairncross, S. and R. Feachem. 1978. Small Water Supplies. Bulletin No. 10. London: Ross Institute and Advisory Service.

Cairncross, Sandy, et. al. 1980. "Health," pp. 75-106. In, Evaluation for Village Water Supply Planning. Chichester, England: John Wiley.

Calvert, R.C. Bakolori Project, a Case Study, Chapter 16. Nigeria: MRT Consulting Engineers.

Camboulives, Marguerite. 1967. L'Organisation Coopérative au Sénégal. Paris: Pedone.

Cameroun, République Unie du. 1983. Société d'expansion et de modernisation de la riziculture de Yagoua: Rapport d'Activité 1982-83. Yagoua: SEMRY.

Cameroun, République du, Ministère de l'Agriculture. 1975. Projet de développement de la riziculture dans la plaine des m'Bos, 4 Volumes. Paris: SATEC.

Cameroun, République Unie du, Ministère de l'Agriculture. 1975. Projet de développement de la riziculture dans la Plaine de M'Bos: Etude de factibilité. Paris: Société d'Aide Technique et de Coopération, 3 Volumes.

Camp Dresser & McKee. 1984. Wash Project. Forty-five Month Contract Summary. Wash Progress Report No. 7, May 31, 1984. Arlington, Virginia: Water and Sanitation for Health Project (contract AID/DSPE-C-0080, Project No. 931-1176).

Campani, R. 1980. "Nature et place de la formation," Périmètre irriguées villageois: Seminaire tenu à Dakar du 21 au 23 avril 1980. Paris: SATEC, pp. 73-77.

Campbell, D.J. 1977. Strategies for Coping with Drought in the Sahel: A Study of Recent Population Movements in the Department of Maradi, Niger, Ph.D. Thesis, Clark University, 285 pp.

Canat, Jean. 1960. Les aménagements hydro-agricoles à Madagascar, 3 Volumes, October 1960. Paris: BDPA, Ministère de la Coopération.

Canat, Jean. 1969. Les traveaux de défrichement et planage du Mangoky. Tananarive: Société pour l'aménagement et le mise en valeur de la vallée du Bas-Mangoky, 84 pp.

Caponera, Dante A. (ed.). 1973. "Water Laws in Moslem Countries, Volume 1," Irrigation and Drainage Paper No. 20/1. Rome, FAO.

Caponera, Dante. A. (ed.). 1978. "Water Laws in Moslem Countries, Volume 2," Irrigation and Drainage Paper No. 20/2. Rome, FAO.

Caponera, Dante A. (ed.). 1979. Water Law in Selected African Countries. Rome: FAO. Legislative Study No. 17, 1.

Caponera, Dante A. 1981. Le droit des eaux dans certains pays Africains. Rome: FAO, 289 pp.

Carlier, Michel. Développment prövissionnel des aménagements hydro-agricoles le long du fleuve Niger, leurs incidences sur les projets de régularisation du fleuve. Rapport de Mission. Paris: Ministère de la Coopération. Niamey: Ministère de l'Economie Rurale; nd.

Carloz, A. 1977. Irrigation des cultures maraîchères, Compte Rendu de Mission, 18 January - 4 February 1977. Abidjan: Ministere de l'Agriculture/SODEFEL, 17 pp.

Carrère, J. 1977. Etude préliminaire en vue de l'éstablissement d'un modèle mathématique du fleuve Niger (Mali et Niger), 2 Volumes. Etudes de données cartographiques et topographique. Paris: IGN.

Carroll, D.M. and C.L. Bascomb. 1967. Notes on the Soils of Lesotho. Ministry of Overseas Development, Tolworth, Surrey, England. Technical Bulletin No. 1.

Carruthers, Ian and A. Weir. 1976. "Rural Water Supplies and Irrigation Development," pp. 288-312. in J. Heyer et al. (eds.) Agricultural Development in Kenya. Nairobi: Oxford University Press.

Carruthers, Ian D., and N. Mountstephens. 1978. "Integration of Socio-Economic and Engineering Perspectives in Irrigation Design." Paper given at: International Commission on Irrigation and Drainage, Tenth Congress, Athens.

Carruthers, Ian D. 1978. "Contentious Issues in Planning Irrigation Schemes," Water Supply and Management, 2, pp. 301-308.

Carruthers, Ian D. and Roy Stoner. 1981. Economic Aspects and Policy Issues in Groundwater Development. World Bank Staff Working Paper, No. 496. Washington, D. C.: The World Bank. 110 pp.

Carruthers, Ian D. and M. Upton. Guidelines for Small Scale Irrigation Development in Africa - Economic Issues. Undated typescript - about Nov. 1982.

Carruthers, Ian D. 198?. Le dévelopement de L'irrigation: Consequences: tirer des expériences recentes pour les les politiques d'aide. Paris: OCDE.

Carruthers, Ian D. 1983. Aid for the Developement of Irrigation. Report on the development assistance committee workshop on "Irrigation Assistance" held in Paris on 29-30 September 1982. Paris: OECD, 166 pp.

Carruthers, Ian. 1985. "Protecting Irrigation Investment: the Drainage Factor," Ceres, vol. 18, no. 4, pp. 15-21.

Carter, R.C. 1984. "Groundwater Retrieval and Delivery for Small Scale Irrigation in Northern Nigeria," pp. 19-35. In, Bauchi State Agricultural Development Programme, Second Fadama Seminar (6-8 March, 1984). Azare, Nigeria: Bauchi State Agricultural Development Programme, Northern Zone.

Carter, R.C., M.K.V. Carr, and M.G. Kay. 1983. "Policies and Prospects in Nigerian Irrigation," Outlook on Agriculture, 12, 2, pp. 73-76.

Cartier. H. Hydrologie du delta du Sénégal (rive gauche du fleuve). Campagne 1964 sur le marigot Lampsar et rap-port de synthèse sur l'hydrologie et le fonctionnement hydraulique des périmètres. June 1965. Paris: Ministère de la Coopération/SOGREAH, 75 pp.

Caso, C. de. 1974. Notes sur le développement de la production rizicole au titre de deuxième phase au projet Zou-Bourgou au Dahomey 1975-1978, 3 Volumes. Paris: CFDT: Ministere de la Cooperation.

Cass, A. 1982. "Irrigation Water Quality of Some Natal Rivers," Water S. A., 8, 3, pp. 155-164.

Casse - Maton - Merand - Robinet. 1974. Lutte contre les effets de la sécheresse Rapport de Mission au Mali, 27 pp. Paris: Ministère des Affaires Etrangères/DAD/SET/ Departement de l'élevage.

Castelino, J.B. and C.P.M. Khamala (eds.). 1979. The Role of Water Resources in Development. Nairobi: National Academy for Advancement of Arts and Sciences, 294 pp.

Caughman, Susan. 1981. "Women at Work in Mali: The Case of the Markala Cooperative." Working Paper No. 50. African Studies Center. Boston: Boston University, 35 pp.

CENECA. 1979. La Mise en oeuvre rationelle des facteurs de production agricole. Paris: Centre National des expositions et concours agricoles.

CENECA. 1980. Agriculture et énergie. Paris: Centre National des expositions et concours agricoles.

Centre for Overseas Pest Research, 1979. Report, January-December 1977. London: Britain. Animal helminthology, pp. 12-13, 25, 86-87, 90-92.

Cernea, Michael M. (ed.) 1985. Putting People First. New York: Oxford University Press for the World Bank, 430 pp.

Chabrolin, Robert. 1973. "Aspects financiers et psychologues de l'intensification de l'agriculture par irrigation," Techniques et Développement, No. 4, pp. 24-28.

Chabrolin, R. 1977. "Rice in West Africa," Leaky, C.L.A. and J.B. Wills Food Crops of the Lowland Tropics, pp. 7-25. Oxford: Oxford University Press.

Chaine, J.P. 1981. Studies of Urinary-Schistosomiasis in the Sahelian Region of the Senegal River Basin, Ph.D. Thesis, Tulane University, 204 pp.

Chakela, Qalabanek. 1981. Soil Erosion and Reservoir Sedimentation in Lesotho. Uppsala: Scandinavian Institute of African Studies, 150 pp.

Chambers, R. 1969. Settlement Schemes in Tropical Africa, A Study of Organisations and Development. London: RKP.

Chambers, R. (ed.). 1970. The Volta River Resettlement Experience. London: Pall Mall Press.

Chambers, Robert and Moris, Jon (eds.). 1973. Mwea: An Irrigated Rice Settlement in Kenya. IFO-Institut Afrika-Studien, no. 83. Munich: Weltforum Verlag, 529 pp.

Chambers, Robert and Moris, Jon. 1977. "Mwea: An Irrigated Rice Settlement in Kenya," Development Digest, vol. 15, no. 4, pp. 75-90.

Chandler, J.A., et al. 1976. "Mosquitoes of the Kano Plain, Kenya. II. Results of Outdoor Collections in Irrigated and nonirrigated areas using Human and Animal Bait and Light Traps," Journal of Medial Entomology, vol. 13, no. 2, pp. 202-207.

Chandler, J.M. 1984. "Cotton Protection Practices in the USA and the World. Section D: Weed Control," pp. 331-361. In: Kohel, R.J. and C.F. Lewis, eds. Cotton. Madison, Wisconsin: American Society of Agronomy.

Chang, Te-Tzu and Benito S. Vergara. 1975. "Varietal Diversity and Morpho-Agronomie Characteristics of Upland Rice," pp. 72-90. In: Major Research in Upland Rice. Manila: International Rice Research Institute.

Chantran, Pierre. 1972. La vulgarisation agricole en Afrique et Madagascar. Paris: Maisonneuve & Larose, 279 pp.

Chapelier, M. 1980. "Place et évolution des périmètres irriguées villageois dans le cadre d'aménagement de grande extension: Presentation du projet N'dombo-Thoiogo (Sénégal)," Périmètre irriguées villageois: Seminaire tenu à Dakar du 21 au 23 avril, 1980. Paris: SATEC, pp. 48-57.

Chapman, N.P. (ed.). 1984. Report of the Second Fadama Seminar held at Azare, March 6-8. Azare, Nigeria: Bauchi State Agricultural Development Programme.

Charlick, R.B. 1974. Power and Participation in the Modernization of Rural Hausa Communities. Ph.D. Thesis, University of California, Los Angeles.

Charnock, G. 1982. "Irrigation at Rahad - Beating the Schisto Problem." African Water and Sewage, August 1982, Vol. 1, No. 2. Redhill UK.

Charoy, J. 1970. Station expérimentale d'hydraulique agricole de Tarna. Exploitation des mesures neutroniques effectuées pour l'étude des relations in situ eau sol-plante. Compte rendu de la campagne de mesures du 1/10/68. Paris: IRAT, 23 pp..

Charoy, J. 1974. "Dynamique de l'eau dans un type de sol du Goulbi de Maradi au Niger, Application à l'irrigation du blé et d'une culture de saison des pluies de coton avec complement d'irrigation," L'Agronomie Tropicale, No. 10, October 1974, pp. 983-994.

Charoy, J. et al. 1978. "Besoins en eau de la canne à sucre," Agronomie Tropicale, 33, No. 4, pp. 344-369.

Charoy, J. F. Forest and J. C. LeGoupil. 1978. Evaluation fréquientielle des besoins d'irrigation pour l'optimisation d'un projet d'aménagement hydro-agricole. Paris: IRAT.

Chaudhry, A.B. 1982. "Drawdown Agriculture as a Suitable Substitute of Traditional Fadama Land Cultivation in the Kainji Lake Basin." pp. 276-285. Polders of the World, Volume 2. Wageningen, Netherlands:

Chaumeny, J. "Le potential irrigable du bassin du fleuve Sénégal," Agronomie Tropicale, No. 11, November 1973, pp. 1079-1088.

Chavancy, Felix, et al. 1976. Bilan et diagnostic des actions entreprises au titre de l'aménagement des vallées des Voltas (1971-1076). Paris/Ouagadougou: Ministère de la Coopération/ Ministère du Développement Rural, 36 pp.

Chaveau, J.P., J.P. Dozon and J. Richard, 1981. "The Changing Fortunes of Rice and Yams: the Case of Central Ivory Coast." Africa. Vol. 51(2), pp. 621-658.

Cheik-Sidia, Mohamed Ould. "L'eau facteur limitif du dévelopment en République Islamique de Mauritanie," Carrier de l'Association de la CEE, No. 14, July-August 1972, pp. 5-7.

Chenel, Schirle, Bertrand, Sordoilet, du Bois, Lazarevitch, Usciati. 1967. Rapport d'une mission d'étude relative à la SAED et au projet d'aménagement hydroagricole de la rive gauche du delta Sénégal. Paris: Ministère de la Coopération, 75 pp.

Cheney, C.S. 1979. A Groundwater Inventory of the GSIO Serowe Block. Botswana: Department of Underground Water Resources.

Chilton, P.J. 1983. "Rural Domestic Supplies from Groundwater--Some Pointers for Planning from the Malawi Experience," pp. 275-295. In, Lium, Tore and Skofteland, E. (eds.) Proceedings, Water Master Planning in Developing Countries. Oslo: Norwegian Committee for Hydrology.

Chilton, P.J.; Grey, D.R.C. and Smith-Carrington, A.K. 1982. Manual for Integrated Projects for Rural Groundwater Supplies. UNDP/Malawi Government, 600 pp.

Chisholm, N. 1983. "Responses of Some Rural Communities in South East Ghana to Economic Recession 1982," Cambridge African Monographs 2. African Studies Centre, Cambridge University.

Choudhry, A.W. 1975. "Potential Effects of Irrigation on the Spread of Bilharziasis in Kenya," East African Medical Journal, vol. 25, no. 3, pp. 120-126.

CIEH. 1978. Carte de planification des ressources en eau de Côte d'Ivoire, du Ghana, du Togo et du Benin, 99 pp. Orléans: BRGM/Agence d'études de geologic appliquée à l'étranger.

CIEH. 1962. Programme d'études des resources en eau du Sénégal. Paris: CIEH, 77 pp.

CILSS - Club du Sahel. 1977. Marketing, Price Policy and Storage of Food Grains in the Sahel: A Survey. Vol. I. Synthesis with Statistical Compilations and Annotated Bibliography. Vol. 2. Country Studies. Paris: CILSS/ Club du Sahel.

CILSS - Club du Sahel. 1977. Office du Niger; Projet de réhabilitation. Court terme, 1978-1982. Ouagadougou: CILSS, Office du Niger, 20 pp.

CILSS - Club du Sahel. 1978. Energy in the developement strategy of the Sahel Situation-perspectives, recommendations. Paris: Club du Sahel, 155 pp.

CILSS - Club du Sahel. 1978. Développement rural intègre d'évaluation des systèmes de production agricole. Synthèse du colloque de Bamako, 20 Février 1er mars 1978. République du Mali: Ministère du développement rural, 176 pp.

CILSS - Club du Sahel. 1978. Energy in the development strategy of the Sahel Situation-perspectives, recommendations. Paris: Club du Sahel, 155 pp.

CILSS - Club du Sahel. 1978. La mise en valeur des terres Neuves au Sahel. Synthèse du seminaire de Ouagadougou, 10-13 October 1978. Paris: Club du Sahel/CILSS, 150 pp.

CILSS. 1979. Development of Irrigated Agriculture in Mali. General overview and prospects. Proposals for a second programme 1980-85. Ouagadougou, Upper Volta. CILSS/Club du Sahel.

CILSS - Club du Sahel. 1979. Etat d'avancement des projects de première génération. Ouagadougou-Paris: CILSS, 109 pp.

CILSS - Club du Sahel. 1979. Cultures irriguées. Fiches techniques du programme de 2éme génération (1980 - 1985) per Equipe production végetale. Mali: CILSS, 39 pp.

CILSS - Club du Sahel. 1979. Cultures irrigués eaux souterraines. Second programme, 1980 - 1985. Fiches techniques. Iles du Cap Vert; CILSS, 26 pp.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in the Cape Verde Islands. Paris: Club du Sahel, 63 pp.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Gambia. General overview and prospects, proposals for a second program 1980 - 1985. Paris: Club du Sahel, 66 pp.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Mali: General overview and projects proposals for a second program 1980-1985. Paris: Club du Sahel, 128 pp.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Mauritania, 86 pp. General overview and prospects, proposals for a second program 1980 - 1985. Paris: Club du Sahel.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Niger. General overview and propects, proposals for a second program, 1982 - 1985. Paris: Club du Sahel, 5 pp.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Senegal. General overview and prospects, proposals for second program 1980 - 1985. Paris: Club du Sahel.

CILSS - Club du Sahel. 1979. Development of Irrigated Agriculture in Upper Volta. Proposals for a second program, 1980 - 1985. Pairs: Club du Sahel, 55 pp.

CILSS - Club du Sahel. 1979. Développement des cultures irriguées en Haute Volta: Propositions pour un second programme 1980-85. Extension de cultures irriguées en Haute Volta. Paris: Club du Sahel.

CILSS - Club du Sahel. 1979. Stratègie et programme de lutte contre la sécheresse et de developpement dans le Sahel. Paris: O.C.D.E., 198 pp.

CILSS - Club du Sahel. 1980. Elements for Livestock Development Strategy in Sahel Countries. Sahel D (80) 73. Maisons-Alfort: Institut d'élevage et de médecine veterinaire des pays tropicaux, 117 pp.

CILSS - Club du Sahel. 1980. Elements for a Livestock Development Strategy in Sahel Countries. Synthesis document. Maisons. Alfort, France: Insititut d'élevage et médecine veterinaire des pays tropicaux, p. 29.

CILSS - Club du Sahel. 1980. Elements de strategie du dévelopement de l'elevage dans les pays saheliens. Tableaux annexes. Sahel D (30) 73. Paris: Institut d'elevage et de medicine veterinaire des pays tropicaux, 63 pp.

CILSS - Club du Sahel. 1980. Meeting on the Development of Irrigated Agriculture in the Sahel. Dakar 20-22 May 1980, summary record. Paris: Club du Sahel.

CILSS - Club du Sahel. 1980. The Sahel Drought Control and Development Program. 1975-1979: A review and analysis. Paris: Club du Sahel, 102 pp.

CILSS - Club du Sahel. 1980. Strategy for Drought Control and Development in the Sahel. Paris: Club du Sahel, 116 pp.

CILSS - Club du Sahel. 1980. The Development of Irrigated Agriculture in the Sahel. Review and perspectives. Paris: Club du Sahel, 34 pp.

CILSS - Club du Sahel. 1981. Hydraulique villageoise et développement rural dans le Sahel, 155 pp. Rapport technique, Sahel D (80) 111. Boad Lomé: Club du Sahel/ CILSS, OCDE.

CILSS - Club du Sahel. 1981. Hydraulique villageoise et développement rural dans le Sahel. Rapport de Synthese. Boad Lomé: Club du Sahel/ CILSS, OCDE, 25 pp.

CILSS - Club du Sahel. 1981. The Recurrent Costs in the Countries of the Sahel. How to Evaluate, Finance and Control Them. Acts of the Ouagadougou Symposium, 11-15 January 1982. Paris: Club du Sahel/CILSS, 592 pp.

CILSS - Club du Sahel. 1982. L'hydraulique villageoise dans le pays membres du CILSS, Situation en Cap Vert. Enquete et propositions en vue d'une gestion rationelle de l'eau, Paris: BURGEAP, OCDE, 100 pp.

CILSS - Club du Sahel. 1982. L'hydraulique villageoise dans les pays membres du CILSS, Situation du Mali. Enquete et propositions en vue d'une gestion/ rationelle de l'eau. Paris: BURGEAP, OCDE, 120 pp.

CILSS - Club du Sahel. 1982. L'hydraulique villageoise dans les pays membres du CILSS, Situation en Mauritania. Enquete et propositions en vue d'une gestion rationelle de l'eau. Paris: BURGEAP, OCDE, 28 pp.

CILSS - Club du Sahel. 1982. L'hydraulique villageoise dans les pays membres du CILSS, Situation au Niger.

CILSS - Club du Sahel. 1982. L'hydraulique villageoise dans les pays membres du CILSS, situation au Sénégal. Enquête et propositions eu vue d'une gestion rationelle de l'eau. Paris: BRGM, OCDE, 130 pp.

CILSS - Club du Sahel. 1982. Développement des cultures pluviales en Haute Volta. Sahel D (82) 177. Paris: Club du Sahel/ CILSS, OCDE, 222 pp.

CILSS - Club du Sahel. 1982. Développement des cultures pluviales au Niger. D (82) 180. Paris: Club du Sahel/ CILSS, OCDE, 293 pp.

CILSS - Club du Sahel. 1982. Village hydraulics in the CILSS, membre countries, situation in the Gambia. Investigation and proposals for rational water management. Paris: OECD, Club du Sahel, 109 pp.

CILSS - Club du Sahel. 1982. Zone d'exploration pour les terres neuves du Sahel. Vol. 2. Cartes. Paris: Club du Sahel/ CILSS, 73 pp.

CILSS - Club du Sahel. 1983. L'hydraulique villageoise dans les pays membres du CILSS. Conditions d'Utilisation, d'entretien des moyens d'exhaurre. Sahel D (83) 208. Ouagadougou; CIEH/ CILSS, 57 pp.

CILSS - Club du Sahel. 1983. Développement des culture pluviales au Mali, Sahel D (83) 192. Paris: Club du Sahel/ CILSS, OCDE, 140 pp.

CILSS - Club du Sahel. 1983. L'hydraulique villageoise dans les pays membres du CILSS, Situation au HAUTE-VOLTA. Enquête et proposition en vue d'une gestion rationelle de l'eau. Paris: CIEH, OCDE, 173 pp.

CILSS - Club du Sahel. 1983. Réunion régionale de synthèse par l'hydraulique villageoise au Sahel. Ouagadougou, 3-5 octobre 1983, compte rendu succint. Paris: Club du Sahel/CILSS, OCDE, 90 pp.

CILSS - Club du Sahel. 1983. Développement des cultures pluviales en Mauritanie. Sahel D (83) 217. Paris: Club du Sahel/CILSS, OCDE, 167 pp.

CILSS - Club du Sahel. 1983. L'aide publique au développement dans les pays membres du CILSS de 1975 à 1982. Vol. 1--Synthèse. Vol. 2--Liste des projets par pays Saheliens et par donateur pour 1982. Sahel D (83) 230. Paris: Clubs du Sahel/ CILSS, OCDE.

CILSS - Club du Sahel. 1983. Développement des cultures pluviales au Sénégal. Sahel. D (83) 216. Paris: Club du Sahel/ CILSS, OCDE, 245 pp.

CILSS - Club du Sahel. 1983. Development of Rainfed Agriculture in the Gambia. Sahel D (84) 243. Paris: Club du Sahel/CILSS, OECD, 116 pp.

CILSS - Club du Sahel. 1983. Development of Rainfed Agriculture in the Sahel. Overview and prospects, fifth conference of the Club du Sahel, Brussels 26 - 28 October 1983. Paris: Club du Sahel, 41 pp.

CILSS - Club du Sahel. 1983. Development of village hydraulics in the Sahel Countries. Overview and prospects synthesis and appendices. Paris: Club du Sahel/ CILSS, OECD, 93 pp.

CILSS - Club du Sahel. 1983. Development of village hydraulics in the Sahel Countries. Overview and prospects, synthesis, Fifth conference of the Club du Sahel, Brussels, 26 - 28 October 1983. Paris: Club du Sahel, 22 pp.

CILSS - Club du Sahel. 1984. Débat national sur la lutte contre la désertification. Tenu Maradi. Niger, du 21 au 28 mai 1984, projet de compte rendu. Paris: Club du Sahel/ CILSS, BEDE, 54 pp.

CILSS - Club du Sahel. 1984. Actualisation du Bilan-Programme Culture Irriguées en Haute Volta: Rapport Générale. Paris: CILSS/Club.

CILSS - Human Resources Unit. 1983. Human resources in the Sahel CILSS-Club du Sahel joint action overview and prospects. Fifth conference of the Club du Sahel. Brussels 26, 27, 29, October 1983. Paris: Club du Sahel/ CILSS, 32 pp.

CINAM. 1977. Sahel et technologies alternatives. Collection technologies et développements. Paris: Ministère de le Coopération, 139 pp.

Cissé, A. 1983. "Développement agricole et participation paysanne: politiques d'aménagements hydro-agricoles au Niger." Paper presented for the International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de L'Eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Cissokho, C. 1974. "Aménagement et équipement du delta sur le fleuve Sénégal," Coopération et Développement, No. 49, April - May 1974, pp. 29-43.

Clark, B.A. 1975. "The Work Done by Rural Women in Malawi," East African Journal of Rural Development, vol. 8, pp. 80-91.

Clark, John I., Mustafa Khogali and Leszek Kosinski (eds.) 1985. Population and Development Projects in Africa. Cambridge, England: Cambridge University Press, 329 pp.

Claus, R. 1982. "La fertilisation de la canne à sucre en Côte d'Ivoire. Etude, Résultats et Recommandations," Agronomie Tropicale, Vol. 37, No. 2, pp. 115-130.

Claus, R. 1982. "Potentiel, Normes et Perspectives de la Canne à Sucre Pluviale dans le Nord de la Côte d'Ivoire," Agronomie Tropicale, Vol. 37, No. 4, pp. 340-353.

Clayton, E. 1983. "Monitoring an Irrigation Project: Mwea, Kenya," pp. 1-21. In, Clayton, E. and Pétry, F. (eds.) Monitoring Systems for Agricultural and Rural Development Projects, vol. 2. FAO Economic and Social Development Paper 12, rev. 1. Rome: FAO.

Clayton, Eric. S. 1978. "A Comparative Study of Settlement Schemes in Kenya," Occasional Paper No. 3, Agrarian Development Unit, Wye College, University of London, 60 pp.

Clayton, E. and Pétry, E. (eds.). 1983. Monitoring Systems for Agricultural and Rural Development Projects. Vol. 2, Case Studies. Rome: FAO, 221 pp.

Cleave, John. 1974. African Farmers. New York: Prager, 153 pp.

Clements, René and Alain, Galand. 1979. Irrigation par aspersion et reseaux collectifs de distribution sous pression. Paris: Eyrolls, 182 pp.

Clowes, M. St. J. and J. H. Wilson. 1974. "Physiological Factors Influencing Irrigation Management of Coffee in Rhodesia," Rhodesia Agricultural Journal, vol. 71, no. 2, pp. 53-55.

Club du Sahel. Fiches de projets d'aménagements hydro-agricoles au Mali. Cultures irriguées. Paris: Club des amis du Sahel, 23 pp.

Club du Sahel. Fiches de projets d'aménagements hydro-agricoles en Mauritanie. Court et moyen terme, equipe des cultures irriguées. Paris: Club des amis du Sahel.

Club du Sahel. Fiches de projets d'aménagements hydro-agricoles au Sénégal. Court et moyen terme, equipe des cultures irriguées. Paris: Club des amis du Sahel, 30 pp.

Club du Sahel. 1977. L'irrigation en Mauritanie. Situation actuelle proposition de programmation. Paris: Club du amis du Sahel, 42 pp.

Club du Sahel. 1977. Proposition de programmation du développement des cultures irriguées en République du Mali. Equipe cultures, irriguées. Paris: Club des amis du Sahel, 80 pp.

Club du Sahel. 1977. Rapport, national Sénégal. Equipe cultures irrigués. Paris: Club du Sahel, 69 pp.

Club du Sahel. 1977. Situation des cultures irriguées dans la République de Gambie. Propositions des programmation équipe cultures irriguées. Paris: Club de amis du Sahel, 24 pp.

Club du Sahel. 1977. Aménagements hydro-agricoles de la plaine de Diré. Programmation des aménagements hydroagricoles. Paris: Club des amis du Sahel, 23 pp.

Club du Sahel. 1977. A Trans-Sahelian Railway and the Development of the Sahel. Paris: Club du Sahel, 99 pp.

Club du Sahel. 1977. Elements pour une programmation des équipements hydro-agricoles 1977-2000. République du Niger: Groupe cultures irriguées, 59 pp.

Club du Sahel. 1977. Equipes Culture Irriguées. Paris: Club du Sahel.

Club du Sahel. 1977. Culture Irriguées: L'irrigation en Mauritanie - situation actuelle - proposition de programmation 1977-2000. Paris: Club du Sahel, 42 pp.

Club du Sahel. 1977. Cultures Irriguées: Rapport National Mauritanie - Fiches de projets d'aménagements hydro-agricole en Mauritanie (court et moyen terme). Paris: Club du Sahel.

Club du Sahel/CLISS. 1977. Marketing, Price Policy and Storage of Food Grains in the Sahel: A Survey. Vol. 1. Synthesis with Statistical Compilation and Annotated Bibliography. Vol. 2. Country Studies. Paris: CLISS/Club du Sahel.

Club du Sahel. 1979. Strategy and program for drought control and developement in the Sahel. Paris: OECD, 178 pp.

Club du Sahel. 1982. The Recurrent Costs in the Countries of the Sahel. How to Evaluate, Finance and Control Them. Acts of the Ouagadougou Symposium, 11-15 January 1982. Paris: Club du Sahel/CLISS, 592 pp.

Cobban, E. 1981. "Monitoring a Sugar Outgrower Project: Vuvulane, Swaziland," Monitoring systems for Agricultural and Rural Development Projects. FAO, Economic and Social Development Paper 12En.

Cobban, E. 1983. "Monitoring a Sugar Outgrower Project: Vuvulane, Swaziland," pp. 58-75. In, Clayton, E. and Pétry, F. (eds.) Monitoring Systems for Agricultural and Rural Development Projects, vol. 2. FAO Economic and Social Development Paper 12, rev. 1. Rome: FAO.

Cocheme, J. and P. Franquin. 1967. An Agroclimatology Survey of a Semiarid Area in Africa South of the Sahara. WMO Technical Note 86. Geneva: WMO, 136 pp.

COGERAF. 1961. Haute Volta - Projet d'aménagement de la Volta Noire. Barrage de Dedougou: Rapport de la mis-sion de Novembre, 1960. Paris: EDF-IGECO, March 1961, 66 pp.

COGERAF. 1961. Pre-étude économique et sociale de 50 sites de barrage, République du Haute Volta, 2 Volumes. Paris: COGERAF, 186 pp.

Colleaux, L.J. 1946. "Les Marais des Régions Montagneuses du Congo Oriéntal." (Revue d'agronomie coloniale.) Bulletin de la SCAIG, Vol. 2, No. 4, pp. 43 à 92.

Collett, J.R. 1976. Field engineering investigations in the Lege Hare River Valley. Oxfam: Addis Ababa.

Colson, Elizabeth. 1971. The Social Consequences of Resettlement. Kariba Studies IV. Manchester, England: Manchester University Press for the Institute for African Studies, University of Zambia, 277 pp.

Comité Interafricain d'Etudes Hydrauliques, 1976. L'Afrique Soudano-Sahelienne. Carte de planification des resources en eau souterraine. Orleans: Bureau de Recherches Géologiques et Minières.

Comité Consultatif sur les innovations techniques. 1977. Expansion des ressources en eau dans les zones arides. Techniques prometteuses et possibilités de recherches. Washington: National Academy of Sciences, 156 pp.

Conac, Francioise. 1985. "Les enjeux de la participation paysanne dans les politiques de l'eau," pp. 1011-113. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Developpement agricole et participation paysannes. Paris: Economica.

Conac, G., Savonnet-Guyot, C. and Conac, F. (eds.) 1985. Les Politiques de l'Eau en Afrique: Deloppment Agricole et Participation Paysanne. Paris: Economica, for the Centre d'études juridiques et politiques de monde Africain, Université de Paris, 767 pp.

Conseil de l'Entente. 1969. Programme de recherche pour les culture irriguées. Abidjan: Conseil de l'Entente.

Conseil de l'Entente. 1979. Programme d'hydraulique villageoise au Togo. Elements complémentaires. Paris: BURGEAP, 27 pp.

Conseil de l'Entente. 1979. Conseil de l'entente programme de recherches pour les cultures irriguées. Abidjan: Conseil de l'entente, 87 pp.

Conseil de l'Entente. 1969. Programme de recherches pour les culture irriguées. Abidjan: Conseil de l'Entente, 87 pp.

Consortium for International Development. 1982. Final Project Evaluation, Tarrafal Water Resources, Cape Verde. Contract Number AFR-C-1403. CID.

Cook, A. 1974. A Photo-Interpretation Study of Soils and Land Use in the Rufiji Basin BRALUP Research Paper No. 34.1. Dar es Salaam: Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam.

Côte d'Ivoire, République du, Ministère de l'Agriculture. 1968. Etude de petite hydraulique agricole 200 bar-rages. Abidjan: Bureau National d'Etudes Techniques de Developpement (BNETD), 206 pp.

Côte d'Ivoire, République du, FAC. Mise en valeur de la Vallée de la Marachoue. Paris: SCET; Abidjan: AVB.

Cotrat, F. (n.d.) "Evolution du secteur agricole de Baguineda, République du Mali," Machinisme Agricole Tropicale, No. 66, pp. 51-59.

Coughenour, M.B., et al. 1985. "Energy Extraction and Use in a Nomadic Pastoral Ecosystem," Science, vol. 230, no. 4726, pp. 619-625.

Couraud, Philippe. 1980. Etude du fonctionnement de quelques unité de production encadrées par la SAED. Paris: INA/PG/IRAT/ISRA, 128 pp. Mimeo.

Coward, E.W. 1983. "Property in Action-Alternatives for Irrigation Investment." Paper presented for the Workshop: Water Management and Policy. Khon Kaen University, Thailand.

Coward, E. Walter, Jr. 1984. Improving Policies and Programs for the Development of Small-Scale Irrigation Systems. (Water Management Synthesis Report 27.) Ithaca, New York: Cornell University.

Coward, E. Walter, Jr. 1985. "Technical and Social Change in Currently Irrigated Regions: Rules, Roles and Rehabilitation," pp. 27-51. In, Cernea, M. (ed.) Putting People First. New York: Oxford University Press.

Coward, E. Walter, Jr., et al. 1986. Watering the Shamba. Current Public and Private Sector Activites for Small-Scale Irrigation Development in Kenya. (Water Management Synthesis Report 40.) Ithaca, New York: Cornell University, 117 pp.

Coyne and Bellier. 1979. Mission d'expertise sur les barrages en pays Dogon. Bamako: Ministère du Développement Rural, 69 pp.

Crawford, Paul R. 1982. AID experience in Agricultural Research: A Review of Project Evaluations. AID Program Evaluation Discussion Paper No. 13. Washington, D.C.: U.S. Agency for International development, 257 pp.

Crousse, Bernard. 1983. "Logique traditionelle et logique d'état- conflits de pratiques et de strategies foncières dans le projet d'aménagement de M'bagne en Mauritanie." Paper at Colloque International de Saint Riquier, France, Pratiques Foncières Locales en Afrique Noire, December.

Crouzet, Etienne. 1983. "Les barrages Africans. Environment problèmes du Sahel," Afrique contemporaine, pp. 23-40. No: 128, Oct.-Nov.-Dec. 1982.

Crow, John E. et al. 1977. L'Environment Economique, Social, et Physique du Département de Zinder, la Republic du Niger. La plannification des ressources naturelles au Niger. Tucson, Arizona: University of Arizona (Natural Resources Project, Preliminary Working Paper), 123 pp.

Cruz, J.F. and B. Cheze. 1979. Etude de groupes motopompes pour l'irrigation. Rapport de mission, 92 pp. Antony: CEEMAT.

Cruz, J.F. 1981. "Les groupes motopompes sur les petits irrigués des fleuves Sahel," Machinisme Agricole Tropical, 73, pp. 3-20.

Crystal, C. 1981. "An Analysis of the Socio-Economic Factors which Distinguish Innovators from Traditional Farmers in the Action Blé Diré Project," (unpublished report). Bamako: USAID/Mali. 83 pp.

CTGREF 1979. Evaluation des quantitiés d'eau necessaires, aux irrigations. Collection techniques. Rurales en Afrique. Paris: Ministère de la coopération, 204 pp.

Cunge - Morvant. 1978. Modèle mathématique du fleuve Niger. Rapport sur la mission d'identification effectuée au Mali et au Niger du 18 Avril au 10 Mai 1978. Paris: Ministère de la Cooperation/COGREAH, 19 pp.

Curfs, H.P.F. 1976. System Development in Agricultural Mechanisation with Special Reference to Soil Tillage and Weed Control - A Case Study for West Africa. Mededelingen landbouwhogeschool, Wageningen, Netherlands, 179 pp.

Dachraoui, A. 1978. Les périmètres villageois de la vallée du fleuve Sénégal. Paris/St. Louis: FAO, 3 Volumes.

Dafalla, H. 1975. The Nubian Exodus. London: C. Hurst & Co.

Dafalla, Hassan. 1969. "Land Economy of Old Halfa," Sudan Notes) and Records, vol. 50, pp. 63-74.

Daget, J. 1977. "La production de poissons de consommation dans les ecosystèmes irrigués," Arid Land Irrigation in Developing Countries (Barton Worthington, E. (ed.)). London: Pergamon Press, pp. 295-302.

Dahomey, République du, Ministère du Développement et du Plan. 1963. Programme d'action pour le département du Sud-Ouest: Les possibilities d'aménagement hydroagricole de la Basse Vallée du Mono. Paris: SCET/SEDES.

Dahomey, République du. SEDAGRI. Aménagements hydro-agricole pilote dans la vallée de l'Ouémé - Programme générale de travail. Paris: SEDAGRI.

Dailot, A. 1961. Observations sur le programme de construction de petits barrages en terre en Haute Volta, Juin 1960. Paris, Aout 1961, 31 pp.

Damson, Mutizwa, Naison. 1981. A Bibliography on Land Tenure and Management in English-Speaking African Countries with Special Reference to Arid Land Problems. Unpublished bibliography, University of Cambridge.

Dancette, C. and A. E. Hall. 1979. "Agroclimatology applied to Water Management in the Sudanian and Sahelian zones of Africa" (Hall, A. E., G. H. Cannell, and H. W. Lawton, (eds.)). Agriculture in Semi-Arid Environments, pp. 98-118. Berlin: Springer Verlag Ecological Studies, 34.

Daniel, C. 1979. "Utilisation du test stomatique pour le controle de l'alimentation en eau en plantation de palmiers à huile," Oleagineux, 34, 6, pp. 283-287.

Darlot, A. 1961. Observation sur les programmes de construction du petits barrages en terre en Haute-Volta, 32 pp.

Da Silva Teixeira, A.J. No date. Provision Map at 1:500,000 (Guinea-Bissau). (Unpublished).

Dasmann, Raymond F., John P. Milton, and Peter H. Freeman. 1973. Ecological Principles for Economic Development. London: John Wiley and Sons, Ltd.

Daum, J.R. 1977. Les eaux souterraines du Sahel. Etude des ressources-Propositions d'etudes. Typologie de captages. Paris: BRGM, 66 pp.

David, Marc. 1962. Etude des possibilité de mise en valeur de la région de la Kolombine du lac Mangui, et de la Térékolé (cercles de Kayes et de Yelimané dans la République du Mali). Paris: BDPA/deBilt (Pays Bas).

David, M. 1965. Etude d'un programme de développement régional dans la préfecture de l'Duham, 3 Volumes. Aménagement des points d'eau, voies de communications, aménagements fonciers, stockage des produits. Paris: BDPA/Ministère de la Coopération.

Davies, H.R.J. 1973. Tropical Africa - an Atlas for Rural Development. Cardiff: University of Wales Press.

Davies, H.R.J. (ed.) 1986. Rural Development in White Nile Province, Sudan. Tokyo: United Nations University, 142 pp.

Davis, Lenwood G. 1976. Irrigation and Water Systems in Africa: An Introductory Survey. Council of Planning Librarians Exchange Bibliography #1206. Monticello, Ill.: Council of Planning Librarians, 24 pp.

Davy, E.G. 1974. A Survey of Studies in Meteorology and Hydrology in the Sudano-Sahelian Zone of West Africa. World Meteorological Organisation Report No. 379, Geneva.

Davy, E.G., F. Mattei, and S.I. Solomon. 1976. An Evaluation of Climate and Water Resources for Development of Agriculture in the Sudano-Sahelian Zone of West Africa. WMO Special Environmental Report No. 9. Geneva: WMO.

Dayem, M.S.A., et al. 1978. "Economic Analysis of Improving a Salt Affected Heavy Soil by Means of the Drainage and Amendments in Egypt." Tenth Congress on Irrigation and Drainage, Athens 1978, Transactions Volume IV. New Delhi: India, International Commission on Irrigation and Drainage.

Dayem, M.S.A., et al. 1978. "A field study to control water table in low permeable salt-affected soil in Egypt," Tenth Congress on Irrigation and Drainage, Athens 1978, Transactions Volume IV.

D'Hoore, J.L. 1964. Soil Map of Africa, Scale 1 to 5,000,000. Lagos.

D'Hoore, J.L. 1968. "The Classification of Tropical Soils," pp. 7-28. In, Moss, R. P. (ed.) The Soil Resources of Tropical Africa. Cambridge, England: Cambridge University Press.

de Baulny, H.L. 1967. The Hydrology of the Manafwa River. Uganda Government: Ministry of Mineral and Water Resources.

de Baulny, H.L. 1970. The Water Balance of Lake Victoria: Technical Note. Uganda: Ministry of Mineral and Water Resources, Water Development Department.

de Boissezon, P., G. Martin, and F. Gras. 1963. "Les sols du Congo." Atlas du Congo. Brazzaville: ORSTOM. (with map at 1:200,000).

D'Costa, V. and A.K. Katyal. 1982. "Irrigation and Drainage Criteria of Some Red Tropical Soils Underlain by Plinthic Gravel." pp. 75-81. J.N. Qureshi (ed). Nairobi, Kenya: Soil Science Society of East Africa.

de Gans, G. 1983. "Loyapat Irrigation Scheme (Turkana District)." Paper presented to Workshop: Small Scale Irrigation in Kenya, Nairobi, Small Scale Irrigation Branch, Kenya Ministry of Agriculture.

de Gans, G. 1983. "Kaputir Irrigation Scheme (Turkana District)." Paper presented to Workshop: Small Scale Irrigation in Kenya. Nairobi: Small Scale Irrigation Branch, Kenya Ministry of Agriculture. As above with more co-operative management style.

de Garine, Igor. 1978. "Population, Production and Culture in the Plains Societies of Northern Cameroon and Chad: The Anthropologist in Development Projects." Current Anthropology, Vol. 19, pp. 42-54.

de Graaf, J. 1986. "Coffee in Kenya," pp. 180-207. In, The Economics of Coffee. Wageningen,Netherlands: PUDOC, 294 pp.

de Groot, W.T. and M. Marchand. 1982. "Kafue Flats, Zambia: Floodplain Planning at the Crossroads," Polders of the World, Vol. 1. Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, pp. 276-287.

de Halleux, B., and A.B. Ergo, W. De Haes, and A.G. Bal. 1972, 1973, 1974(?). Bibliographie Analytique pour l'Agronomie Tropicale. Zaire, Rwanda, Burundi. (Analytic Bibliogrpahy for Tropical Agronomy. Zaire, Rwanda, Burundi) FR. Three volumes, Centre d'Informatique Appliquée au Développement et à l'Agriculture Tropicale (CIDAT). Tervuren, Belgium: Musée Royal de l'Afrique Centrale. Volume I, 243 pp. Volume II, 225 pp. Volume III, 3 microfiches.

de Mabior, J.G. 1981. Identifying, Selecting, and Implementing Rural Development Strategies for Socio-Economic Development in the Jonglei Projects Area. Ph.D. Thesis, Iowa State University, 288 pp.

de Meredieu, J. 1959. Intérêt des aménagements hydro-agricole de petites et moyennes dimensions en Afrique noire. Rome: FAO, 77 pp.

de Ridder, N., L, Stroosnijder, A.M. Cisse, and H. Van Kenlen. 1982. Productivity of Sahelian Rangelands: A Study of the Soils, the Vegetations, and the Exploitation of that Natural Resource. Wageningen: Wageningen Agricultural University.

de Villiers, A. 1978. "A New Approach for the Planning and Development of Smallholder Irrigation Schemes in the Black states of South Africa," Agrekon, 17, 4, pp. 8-13.

de Wilde, John C. et al. 1967. "Mali: The Office du Niger--An Experience with Irrigated Agriculture," pp. 245-300. In, Experiences with Agricultural Development in Tropical Africa. Vol. 2. Case Studies. Baltimore: Johns Hopkins Press.

de Wilde, John C. 1984. Agriculture, Marketing, and Pricing in Sub-Saharan Africa. Los Angeles, CA: African Studies Center and African Studies Association, University of California, Los Angeles. 129 pp.

Debenham, F. 1952. Study of an African Swamp. London: Colonial Office (HMSO).

Debenham, F. 1948. Report on the Water Resources of the Bechuanaland Protectorate, Northern Rhodesia, The Nyasaland Protectorate, Tanganyika Territory, Kenya and the Uganda Protectorate. London: HMSO.

Deitchman-Boulet, E. 1979. Irrigated Vegetable Production Around N'Djamena, Chad, mimeo, 11 pp.

Delgado, Felisa. 1975. Méthode d'évaluation des investissement de mise en valeur des ressources hydrauliques (Thèse). Université de Montpellier I.

Dent, D. and J. Aitken. 1983. "What Kind of a Survey is Appropriate?," Irrigation in Tropical Africa, Problems and Problem Solving, African Studies Centre Workshop, 24-25 March, University of Cambridge, UK.

Dent, David and Aitken, John. 1984. "Soil Survey for Irrigation: a Case Study of Bacita Estate, Nigeria," pp. 27-39. In, Adams, W. M. and Grove, A. T. (eds.) Irrigation in Tropical Africa. Cambridge African Monographs, No. 3. Cambridge, England: African Studies Centre, Cambridge University.

Department of Rural Development--Federal Ministry of Agriculture. 1982. Gusau Agricultural Development Project--Project Completion Report, April 1982. Agricultural Projects Monitoring, Evaluation and Planning Unit, PMB, 2178, Kaduna, Nigeria.

Derman, William. 1980. "Cooperatives, Initiative, Participation and Socio-Economic Change," pp. 605-702. Reyna, Stephen P. (ed.) Sahelian Social Development. Abidjan: REDSO/USAID.

Derman, William. 1984. "USAID in the Sahel," pp. 77-97. In, Barker, Jonathan (ed.) The Politics of Agriculture in Tropical Africa. Beverly Hills, CA: Sage Publications.

Deroo, Geert. 1978. Les problèmes d'eau en matière de dévelopment rural et les pompes manuelles. Manuel technique de calcul des pompes. Paris: L.U.C.

Des Bouvrie, C. 1975. Perspective Study for Agricultural Development in the Countries of the Sahel Zone: Irrigation Development in Mali, Niger and Upper Volta. Accra: FAO.

Des Bouvrie, C. and J.R. Rydzewski. 1977. "Irrigation," Food Crops of the Lowland Tropics eds., Leaky, C. L. A. and J. B. Wills, pp. 161-163. Oxford: Oxford University Press.

Deuse, J.P.L., S. Hernandez, J.P. Aubin, and L. Keita. 1980. "Essai de lutte chimique contre les riz sauvages annuels au Sénégal," Agronomie Tropicale, Vol. 35, No. 1, pp. 47-53.

Deuse, J.P.L. and D. Bassereau. 1980. "Mise au Point sur le Désherbage de la Canne à Sucre de l'Afrique de l'Ouest Francophone," Agronomie Tropicale, Vol. 35, No. 1, pp. 84-85.

Deutsch, Morris; Wiesnet, D. R. and Rango, A. (eds.) 1981. Satellite Hydrology. (Proceedings of the Fifth Annual William T. Pecora Memorial Symposium on Remote Sensing, Sioux Falls, South Dakota, June 10-15, 1979.) Minneapolis: American Water Resources Association.

Deutsches Institut fur Afrika Forschung. 1975. Drought in Africa. A Selected Bibliography. Hamburg: Deutsches Institut fur Afrika Forschung, Dokumentations-Leitstelle; about 200 annoted titles indexed in English, French and German.

Development Alternatives, Inc. 1982. A Strategy for the Development of Four Districts in Western Kenya. Washington, D. C.: Development Alternatives, Inc.

Development Alternatives, Inc. 1982. Agricultural Sector Assistance Strategy for Upper Volta. Washington, D.C.: Development alternatives, Inc., 204 pp.

Development Alternatives, Inc. and Research Triangle Institute. 1982. Sudan Agricultural Strategy Assessment: Summary Report. Washington, D. C.: Development Alternatives, Inc.

Dewez, J. 1959. "La Culture de l'Arachide dans la Plaine de la Ruzizi," Bulletin d'Information de l'INEAC, Vol. 8, No. 4, pp. 219-230.

Dewez, J. 1960. "La Culture Cotonnière dans la Plaine de la Ruzizi." Bulletin d'Information de L'INEAC, Vol. 9, pp. 161 à 176.

Dewez, J. and J. Catzeflis. 1959. "Le Riz dans la Vallée de la Ruzizi," Bulletin d'Information de l'Institut Nationale pour l'étude Agronomique du Congo Belge, Vol. 8, No. 6, pp. 341-354.

Dey, J. 1980. Women and Rice in The Gambia: The Impact of Irrigated Rice Development Projects on the Farming Systems. Ph.D. Thesis, Univ. of Reading, England, 381 pp.

Dey, J. 1980. "The Socio-Economic Organisation of Farming in the Gambia and its Relevance for Agricultural Development Planning," Agricultural Administration Network Paper 7, Overseas Development Institute, London, 42 pp.

Dey, J. 1981. "Gambian Women: Unequal Partners in Rice Development Projects?" Journal of Development Studies, vol. 17, no. 3 (April), pp.

Dey, J. 1982. "Development Planning in The Gambia: the Gap between Planners' and Farmers' Perceptions, Expectations and Objectives," World Development, 10, 5, pp. 377-396.

Dey, J. 1984. Women in Rice-Farming Systems. Focus: Sub-Saharan-Africa. Women in Agriculture, No. 2. Rome: FAO, 106 pp.

Dey, J. 1985. "Women in African Rice Farming Systems," pp. 419-443. In, IIRI, Women in Rice Farming. Aldershot, U.K.: Gower.

DGRST 1980. Les politiques d'aménagement. Hydro agricole en Afrique Sahelienne, 15 pp. Action complémentaire coordonée, Lutte contre, l'aridité en milieu tropical, contribution à un bilar. Paris: SEDES, IRAM.

DHV, 1979. Shallow Wells, second edition. Amersfoort, Netherlands: DHV Consulting Engineers.

Dia, Oumar, Kassimou. 1985. "Le role des sociétés de développement: le case de la SAED," pp. 567-580. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Développement agricole et participation paysanne. Paris: Eocnomica.

Diab, M.S. 1982. "Polder Areas of Northern Localities of the Nile Delta," Polders of the World, Volume 1. Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, pp. 75-85.

Diagne, P.S. 1974. La delta du fleuve Sénégal: Problèms de développement. Doctoral Thesis, Univ. of Paris.

Diagne, P.S. 1976. "Une expérience originale: les petits périmètres de Matam," Notes Africaines (IFAN), No. 149, January 1976, pp. 8-10.

Diagne, P.S. 1979. "Les modèles d'intervention de la SAED," Maitrise de l'espace agraire et développement en Afrique Tropicale, Paris: Editions de l'Office de la Recherche Scientifique et Technique Outre-Mer, pp. 341-346.

Diallo, Ibrahima. 1975. Modernisation agricole et changements sociaux: les conditions de vie des paysanne des terres irrigués de l'Office du Niger au Mali. Bamako: IER, 261 pp.

Diallo, M. 1980. "Comparative Analysis of Capital Intensive and Labor Intensive Rice Irrigation Perimeters in the Senegal River Valley." Unpublished M.S. Thesis, Department of Agricultural Economics, Michigan State University, East Lansing.

Diamant, B.Z. 1980. "Environmental Repercussions of Irrigation Development in Hot Climates," Environmental Conservation, 7, 1, pp. 53-58.

Diarra, Marthe. 1982 Aménagement hydro-agricole d'Ibohamane: Document 5. Contribution à l'analyse des effets de l'aménagement sur les femmes dans les domaines de l'artisanat du commerce, de l'élevage, et des relations sociales Tahoua (Niger). Projet FAO Formation, Module Suivi, Atelver Finale, Mimeo.

Diarra, Ngolo. 1979. "Le jardinage urbain et surbain au Mali--les cas de Bamako," Journal d'Agriculture Tropicale et de Botanique Appliqué, Vol. 22, Oct.-Dec., pp. 359-364.

Dieleman, et-al. 1976. Drainage Testing. Rome: F.A.O., 172 pp.

Diemer, Geert and Ellen C. W. van der Laan. 1983. "Small-Scale Irrigation Along the Senegal River." Irrigation Management Network Paper 8b, London: Overseas Development Institute.

Diemer, Geert and Ellen van der Laan. 1983. "Using Indigenous Skills and Institutions in Small-Scale Irrigation: An Example from Senegal," Irrigation Management Network Paper, 8b. London: Overseas Development Institute, 11 pp.

Diluca, C. and E. deRegimes. 1983. Forage d'eau. Materiel et techniques mis en oeuvre en Afrique centrale et de l'ouest. Paris: Ministère des relations extérieures, 273 pp.

Dinham, B. and Hines, C. 1983. Agribusiness in Africa. London: Earth Resources Research.

Direction Generale a la Recherche Scientifique et Technique (DGRST), Le Politiques D'Aménagement Hydro-Agricole en Afrique Sahelienne Contribution à un Bilan. Societe d'études pour le developement Economique et Sociale (SEDES). Institut de Recherces et d'Applications de Méthodes de Développement (IRAM-Paris). January 1980.

Dissou, M. 1983. "Aspects de la participation paysanne à l'exploitation du project de la palmeraie irriguée de Ouidah-Nord (Sud Benin)," Colloque International Développement agricole et participation paysanne. Un example: Les Politiques de L'eau. Université de Paris, 14-15 October.

Dognin, O., C. Megie, L. Richard and G. Sement. 1980. Dynamics of Exchangeable-Potassium in Cultivated Tropical Soils. (In French) Paris: IRCT.

Doherty, Victor. 1982. Tank Irrigation in Crosscultural Perpective. India: ICRISAT.

Donahue, Roy L. (no date). Soils of Equatorial Africa and their Relavance to National Agricultural Development. Michigan State University Institute of International Agricİture, Research Report No. 7.

Donarski, Jerzy; Heath, Robert W. and Wallace, John B. 1983. "Training through Consultancy to Improve Maintenance Management," Journal of European Industrial Technology, vol. 7, no. 3, pp. 10-16.

Donev. P. 1983. "Eutric Planosols in the Shokue Region of South Mozambique and their Suitability for Rice Growing." (In Bulgarian). Pochvoznanie i Agrokhimiya, 18(1):10-15.

Donev, P. 1983. "Soil Characteristics of Arenosols (Luvic arenosols, Albic arenosols) in the Shokue Region of South Mozambique." (In Bulgarian). Pochvoznanie i Agrokhimiya. 18(1):16-20.

Doorenbos, J. and M. Smith. 1977. Water Use in Irrigated Agriculture, Democratic Republic of Somalia - A Country Brief. Food and Agriculture Organisation of the United Nations, Rome.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper 24, Rome: Italy, FAO.

Doorenbos, J.R. and A.H. Kassam. 1979. Yield Response to Water, FAO Irrigation and Drainage Paper 33, Rome: Italy, FAO.

Doppler, W. 1976. A Shift in Production and its Consequences for the Gezira Irrigation Project in the Sudan. Zeitschrift fur Auslandische Landwirtschaft, Vol. 15, No. 4, 1976, pp. 477-492, 14 ref, 6 tab., in German; summary in English.

Dorner, Heiver. 1978. "L'emploi des energies eoliennes et solaires pour, l'approvisionement en eau," Revue générale Africaine des travaux l'industrie des mines et des public, pp. 9-16. No. 18.

Doxiadis Ionides Associates Ltd. 1961. Preliminary Study on the Waters of Somalia. London: Doxiadis Ionides Associated Ltd.

Dozon, J.P. 1978. "Logique des développeurs, realité des développés, bilan dune experience développement riziculture en Côte d'Ivoire". Mondes en Développement, 24, pp. 909-934.

Drachoussoff, V. 1959. "Le Génie Rural au Congo Belge," Annales de Gembloux, Vol. 65, No. 3, pp. 245-252.

Dravignan, Francois de. 1977. "Un village au Niger devant les experts occidentaux," Le Monde Diplomatique, No. 284, Novembre.

Dregne, H.E. (ed.). 1977. Managing Saline Waters for Irrigation: Planning for the Future. (Proceedings of the International Salinity Conference, Lubbock, Texas, 16-20 August 1976.) Lubbock, Texas: Texas Technical University, 624 pp.

Dregne, Harold E., ed. 1970. Arid Lands in Transition. Papers presented at an international conference on "Arid Lands in a Changing World", sponsored by the American Association for the Advancement of Science and UNESCO and held in June 1969 at the University of Arizona in Tucson. Baltimore, Maryland: American Association for the Advancement of Science.

Drijver, C.A. and Marchand, M. 1985. Taming the Floods: Environmental Aspects of Floodplain Development in Africa. Leiden: Centre for Environmental Studies, State University of Leiden.

Dubois, B. 1967. "La société Malagache d'aménagement du lac Alaotra," Industries et Travaux d'outre mer. April 1967.

Dubois, J. et. al. 1983. Aménagement de marigot prés de Bakel (Senegal). Serie Etudes et Recherches, No. 81/83, mars. Dakar: ENDA, 65 pp.

Dubreuil, P. 1961. Aménagements des lacs Télé et Faguibine: Etudes hydro-climatiques. Paris: ORSTOM. 1961.

Dubreuil, P. et al. 1972. Recueil des données de base des bassins representatifs et experimentaux. Paris: ORSTOM.

Dudal, R. 1980. "The Earth's Land Resources: A World Soil Map." (In German). Mitteilungen der Osterreichischen Bodenkundlichen Gesellschaft, No. 22:7-13.

Dumont, René. 1961. Rapport de visite de l'Office de Niger de M.le Professeur René Dumont. Mars 1961, 21 pp.

Dumont, Rene. 1965. Développement agricole africain. Paris: PHF, 223 pp.

Dumont, M. and M. Schirie. 1967. Entretien de réseaux hydro-agricole à Madagascar, 3 Volumes. Paris: SEAE.

Dumont, René. 1966. False Start in Africa. Sphere Books/ Andre Deutsch.

Dumont, René and Marie-France Mottin. 1982. Le défi Sénégalais: reconstraire les terroirs, liberers les paysans. Dakar: ENDA, 68 pp.

Dupriez, H. 1979. Integrated Rural Development Projects Carried Out in Black Africa with EDF Aid. Evaluation and Outlook for the Future. Collection Studies, Development Series, EEC #1, 254 pp.

Dupuis, J. and R. Hlavek. 1970. La subdivision d'outillage mécanique de l'hydraulique (SOMH). Rapport de mission 18/4 - 13/5 1970. Paris: SEAE, Ministère de l'agriculture, 65 pp.

Duranton, J.F., M. Lanois, M. Lanois-Luong, and M. LeCocq. 1981. "Recherches sur les ravageurs des cultures vivrières au Sahel: Le cas des sauteriaux," Agronomie Tropicale, Vol. 36, No. 2, pp. 178-183. An update on acridien research in the Sahel.

Durnford, D.S. 1982. Optional Drain Design: An Incremental Net Benefit Approach. Ph.D. Thesis, Colorado State University, 283 pp.

East African Meteorological Department. 1981. Collected Climatological Statistics for East African Stations. Nairobi, Kenya: African Meteorological Department.

Easter, K. William. 1980. Issues in Irrigation Planning and Development. Staff Paper P80-5. St. Paul, Minnesota: Department of Agriculture and Applied Economics, University of Minnesota, 32 pp.

Easter, K. William. 1986. "Introduction and Conceptual Model," pp. 1-11. In, Easter, K.W. (ed.) Irrigation Investment, Technology, and Mangement Strategies for Development. Boulder, CO: Westview Press.

Easter, K. William. (ed.) 1986. Irrigation Investment, Technology, and Management Strategies for Development. Boulder: Westview Press.

Ebrahim, M.H.S. 1983. "Irrigation Projects in Sudan: the Promise and the Reality," Journal of African Studies 10, 1, pp. 2-13.

Echard, Nicole. 1964. Etudes socio économiques dans les vallées de l'Ader Doutchi Maggia. Paris/Niamey: Etudes Nigeriennes, No. 15.

Eckebil, Dr. Jaques-Paul. 1983. Recent Examples of Areas of Priority in Research. Courier No. 82, Nov-Dec 1983, CEC, Brussels.

EDIAFRIC. 1975. Les dossiers sahel; les cultures irriguées et les aménagements hydro-agricoles dans le cadre des deux premiers programmes, Vol. 3. Paris: EDIAFRIC.

EDIAFRIC. 1976. L'économie des pays du Sahel; l'eau et l'irrigation. Paris: EDIAFRIC, 212 pp.

EDIAFRIC. 1978. Le dossier Sahel: L'irrigation et l'autosuffisance alimentaire al'horizon 2000. Paris, 332 pp.

Edou, O. "Problèmes posés par la gestion des ensembles de petits périmètres--cas de Mauritanie," Périmètre irriguées villageois: Seminaire tenu a Dakar du 21 au 23 avril 1980. Paris: SATEC.

Edwards, C.B. and L.F. Vincent. 1981. Irrigation in Zambia: Prospects and Policies for the Poorest Farmers. Discussion paper 139, School of Development Studies, University of East Anglia, England.

Edwards, K.A., Classen, G.A. and Schroten, E.H.J. 1983. The Water Resource in Tropical Africa and Its Exploitation. ILCA Research Report No. 6. Addis Ababa, Ethiopia: International Livestock Centre for Africa, 103 pp.

Ega, Alegwu L. 1984. "Land Acquisition and Land Transfer in Zaria Villages in Nigeria," Agricultural Administration, Vol. 15, No. 2, pp. 87-100.

Eicher, Carl. 1982. "Facing Up to Africa's Food Crisis," Foreign Affairs, vol. 61, no. 1 (Fall), pp. 151-174.

Eicher, Carl K. and Doyle C. Baker. 1982. Research on Agricultural Development in Sub-Saharan Africa: A Critical Survey. MSU International Development Paper No. 1. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University.

Eckenfelder, G.V. 1980. "Hydro power plans in Nigeria," In, Smil, Vaclav and Knowland, W. E. (eds.) Energy in the Developing World. London: Oxford University Press, p. 278.

el Agraa, Omer, et. al. 1980. "The Sudan: Human Settlements in Gezira," pp. 287-289. In, B.S. Bhooshan (ed.) Towards Alternative Settlement Strategies. New Delhi: Heritage Publisher.

el Agraa, Omer M.A., et al. 1986. "The Gezira Region, The Sudan," pp. 80-130. In, Hardoy, Jorge and Satterthwaite, David (eds.) Small and Intermediate Urban Centres: Their Role in Regional and National Development in the Third World. London: Hodder and Staougnton.

el-Bagir, Ibrahim, et al. 1984. Labour Markets in the Sudan. Geneva: International Labour Office, 224 pp.

el-Baz, Farouk. 1979. "Monitoring the Desert Environment from Space," pp. 383-398. In, Bishay, Adli and McGinnes, W. (eds.) Advances in Desert and Arid Land Technology and Development, vol. I. New York: Harwood Academic Publishers.

el Hadari, A.M. 1972. "Irrigated Agriculture in the Sudan: New Approaches to Organisation and Management," Indian Journal of Agricultural Economics, Vol. 27, No. 2, pp. 25-37.

el Hadari, A.M. 1971. "Occupational Immobility of Tenants on the Gezira Scheme, Sudan," East African Journal of Rural Development, Vol. 4, No. 2, pp. 67-75.

el-Karouri, M.O.H. 1979. Effect of Soil Salinity on the Productivity of Arid Lands, with Special Reference to the Sudan. National Council for Research, Khartoum, Sudan. Proceedings of the Khartoum Workshop on Arid Lands Management. The University of Khartoum - The United Nations University 22-26 October 1978 (J. A. Mabbutt, ed.), Tokyo, Japan, pp. 49-54, 6 tab, 14 ref.

el Sammani, Mohammed Osman. 1985. "Migrant Labour in the New Halfa Scheme," pp. 272-281. In, Clarke, John, et al. (eds.) Population and Development Projects in Africa. Cambridge, England: Cambridge University Press.

Elliot, Fred C., Marvin Hoover, and Walter K. Porter. 1968. Advances in Production and Utilization of Quality Cotton: Principles and Practices. Ames, Iowa: Iowa State University Press.

Ellman, A. L. (ed.) 1979. Proceedings of the Commonwealth Workshop on Irrigation Management. London: Commonwealth Secretariat.

Elmendorf, M. 1976. "Bura Irrigation Settlement Scheme--Tana River District, Kenya." Washington D.C.: The World Bank.

Emmanuel, H.W. 1975. Land Tenure, Land-use, and Development in the Awash Valley--Ethiopia. Unpublished Paper. Land Tenure Centre, University of Wisconsin (LTC No. 105).

Erhabor, P.O. 1982. Efficiency of Resource Use Under Small-Scale Irrigation Technology: A Case Study of Shadouf and Pump in Ringim, LGA, Kano, Nigeria. Ph.D. Thesis, Purdue University, 195 pp.

Espallarageas, Michel. 1983. "L'autorité du bassin du Niger. La coopération interafricaine pour l'utilization et l'aménagement du bassin du Niger." Le mois en Afrique, No. 205, Feb., March, 1983, pp. 114-126.

Europe Outremer. 1983. "L'eau en Afrique: La grande soif du continent," Europe Outremer, No. 643-644, pp. 1-48.

European Communities Commission. 1982. Development of the Senegal River Valley. Spokesman's Group, Europe Information: Development, No. 39. Order No. X/339/82.

Evett, Steven Roy, 1979. An Evaluative Report on the Niger Marshlands Survey Project. (Niamey, Niger): U.S. Agency for International Development.

Fadl, Osman and Bailey, Charles (eds.) 1984. Water Distribution in Sudanese Irrigated Agriculture: Productivity and Equity. Wad Medani, Sudan: University of Gezira, 151 pp.

Fagbami, A. 1981. "SLAR Imagery Interpretation of Eastern Niger Delta for Soil Survey Purposes." pp. 191-202. Technical Papers of the American Society of Photo-grammetry. In 80's area of change. Fall Technical Meeting 1981.

Fahim, Hussein. 1980. "Nubian Resettlement and Nomadic Sedentarization in Khashm el Girba Scheme, Eastern Sudan," pp. 140-156. In, Salzman, Philip C. (ed.) When Nomads Settle. New York: Praeger.

Fahim, Hussein M. 1981. Dams, People and Development: The Aswan High Dam Case. New York: Pergamon Press, 187 pp.

Fahim, Hussein. 1983. Egyptian Nubians--Resettlement and Years of Coping. Salt Lake City, University of Utah Press, 195 pp.

Faki, H. 1982. "Disparities in the Management of Resources between Farm and National Levels in Irrigation Projects; Example of the Sudan Gezira Scheme," Agricultural Administration, Vol. 9, No. 1, pp. 47-59.

Falciai, Mario. 1981. "Essais d'Irrigation Goutte à Goutte du Bananier dans la Vallée du Chebeli (République Democratique Somalie)," Transactions XIth Congress, International Commission on Irrigation and Drainange, Grenoble, 1981.

Falkenmark, M. and Lundqvist, J. (eds.) 1984. Water for All. Tema V Report, 9, 1984. Linköping, Sweden: Dept. of Water in Environment and Society, University of Linköping.

Falkenmark, Malin (ed.) 1982. Rural Water Supply and Health. The Need for a New Strategy. Uppsala: Scandinavian Institute of African Studies, 118 pp.

Fall, Moussa. 1980. "Socio-Economic Aspects Involved in Introducing New Technology into the Senegalese Rural Milieu," In ICRISAT, Proceedings of the International Workshop on Socio-Economic Constraints to the Development of Semi-Arid Tropical Agricultural. Patancheru, India: ICRISAT.

Family Health Care, Inc. (Victor Barbiero). 1979. Health Impact Guidelines for the Design of Development Projects i. the Sahel. 2 Vols. Washingon, D.C.

Fanfant, R. 1970. Physiographic Units and Main Soil-Groups ofLiberia. Food and Agriculture Organization, Rome. (Unpublished). (With provisional map of Liberia).

Faniran, A. and L.K. Jeje. 1983. Humid Tropical Geomorphology. London: Longmans.

FAO. 1964. Rapport aux gouvernements du Sénégal et de la Gambie sur les possibilities d'aménagement agricole intégré du bassin fleuve Gambie. Rome: FAO, 67 pp.

FAO. 1967. Agricultural and Water Surveys: Somalia. FAO/SF:36, Rome. (with map).

FAO. 1968. Definitions of Soil Units for the Soil Map of the World. FAO World Soil Resources Reports, no. 33. Rome: FAO/Paris: UNESCO, 72 pp.

FAO. 1968. Survey of the Irrigation Potential of the Lower Tana River Basin, Kenya, Final Report. Rome: FAO.

FAO. 1970. Bibliography on Land Tenure in Africa. Rome: FAO (Rural Institutions Division).

FAO. 1971. Bibliography of FAO Documents on Niger. Rome: FAO (microfiche), B. C21.

FAO. 1971. Programmes d'irrigations dans les villages; vers une utilisation rationnelle de l'eau. Rome: FAO.

FAO. 1972. Bibliography of FAO Documents on Mali. Rome: FAO (microfiche), B. 035.

FAO. 1972. Bibliography of FAO Documents on Upper Volta. Rome: FAO (microfiche), b. 040.

FAO. 1972. The Employment of Draught Animals in Agriculture. Rome: FAO, 249 pp.; reiss... in English of French work prepared in 1968.

FAO. 1973. Bibliography of FAO Documents on Senegal. Rome: FAO (microfiche), B. 105.

FAO. 1973. Groundwater Models. FAO Irrigation and drainage paper 21. Rome: Food and Agriculture Organisation.

FAO. 1973. Irrigation, Drainage and Salinity: an International Source Book. Rome Italy: FAO.

FAO. 1973. Pilot Irrigation Scheme, Asutsuare, Ghana: Agronomy. Rome: FAO.

FAO. 1973. The Sahelian Zone. A Selected Bibliography for the Study of its Problems. Rome: FAO library occasional bibliographies.

FAO. 1974. Soil Map of the World. Volume I: Legend, Paris: UNESCO.

FAO. 1976. La défense des terres cultivées contre l'érosion hydraulique. Rome: FAO.

FAO. 1976. La défense terres cultivées contre l'erosion hydraulique. Rome: F.A.O., 202 pp.

FAO. 1977. Club du Sahel: groupe des cultures irriguées. Rapport Générale. Rome: FAO, 82 pp.

FAO. 1977. Les Systèmes Pastoraux Saheliens. Rome: FAO.

FAO. 1977. Soil Map of the World. Volume VI: Africa. Paris: UNESCO.

FAO. 1978. "Report on the Agro-ecological Zones Project," Vol. 1. Methodology and Results for Africa. Rome: Food and Agriculture Organisation.

FAO. 1979. Soil Surface Investigations for Irrigation. Washington, D.C.: FAO.

FAO. 1979. Soil Survey Investigations for Irrigation. FAO Soils Bulletin 42. Rome: Food and Agriculture Organisation.

FAO. 1980. Background to Agricultural Development in Central Province, Zambia. Rome: FAO. Norwich: Overseas Development Group.

FAO. 1981. "Fourth meeting of the West African subcommittee for soil correlation and land evaluation, Banjul, Gambia, 20-27 October 1971" World Soil Resources Report No. 53.

FAO. 1981. Man's Influence on the Hydrological Cycle. Irrigation and Drainage Paper, Special Issue 17. Rome: FAO, 71 pp.

FAO Agricultural Department, Rome. 1981. Rice Production in the ACP Countries. The Courier No: 66, March-April 1981.

FAO. 1982. "Après une enquête detaillée auprés de quatre périmètre," Conference, Analyse de Périmètre Irriguée Villageois (PIV) de la Zone Matam. Rome: FAO, 125 pp.

FAO. 1982. Farmers' Participation and Organization for Irrigated Water Management. Rome: FAO Land and Water Division.

FAO. 1982. Guidelines--Women in Land and Water Development. Rome: FAO Land and Water Development Division.

FAO. 1983. Integrating Crops and Livestock in West Africa. FAO Animal Production and Health Paper, no. 41. Rome: FAO, 112 pp.

FAO. 1986. Irrigation in Africa South of the Sahara. A Study, with Particular Reference to Food Production. Rome: FAO Investment Center, FAO (Report No. III/85 CP-SSA 2), 75 pp. plus annexes.

Fapohunda, H.O. 1980. River Basin Sequential Water Use and Salinity Effects on Crop Yield Economics. Ph.D. Thesis, Utah State University, 315 pp.

Farah, S.M. 1983. "Effects of Supplementary Irrigation on Rain-Grown Sorghum (Sorghum bicolor) in the Sudan," Journal of Agricultural Science, UK, 100, 2, pp. 323- 327.

Farbrother, H.G. 1984. "Modernisation of Indenting in the Gezira," pp. 78-93. In, O. Fadl and C. Bailey (eds.) Water Distribution in Sudanese Irrigated Agriculture: Productivity and Equity. Wad Medani, Sudan: University of Gezira.

Farid, M.A. 1977. Irrigation and Malaria in Arid Lands, Arid Land Irrigation in Developing Countries (Barton Worthington, E. (ed.)). London: Pergamon Press, pp. 43-422.

Farmer, Grahan. 1986. "Rainfall Variability in Tropical Africa: Some Implications for Policy," Land Use Policy, vol. 3, no. 4, pp. 336-342.

Farr, J.L., et al. 1979. Hydrogeological Investigations into the Karoo Formations of the Dibete Area, Kgatleng District. Botswana: Department of Geological Survey.

Farvar, M. Taghi and Milton, John P., eds. 1972. The Careless Technology--Ecology and International Development. The Record of the Conference on the Ecological Aspects of International Development Convened by the Conservation Foundation and the Center for the Biology of Natural Systems, Washington University, December 1968, Warrenton, Virginia. New York: Natural History Press.

Fauchon, J. 1980. "Oasis Agriculture: How Pumps Divide the Peasantry," Ceres, 13, pp. 41-45.

Fauchon, J. 1981. "Some Other Costs of Development," Ceres 14(5) pp. 33-35.

Fauck, R. 1981. "Dry Soils of the African Sahel." pp. 72-80. F.H. Beinroth and A. Osman (eds.). Proceedings of the Third International Soil Classification Workshop. Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Damascus, Syria.

Faye, M. 1971. Etude d'hydraulique agricole: Barrages de Tamatougou et Bougou. Paris: BDPA, 76 pp.

Faye, J., and M. Niang. 1979. "Une Expérience du Restructuration Agraire et d'Aménagement de l'Espace Rural," Maitrise de l'Espace Agraire et Développement en Afrique Tropicale. Paris: Editions de l'Office de la Recherche Scientifique et Technique Outre-Mer, pp. 111-114.

Feachem, R., M. McGarry and D. Mara (eds.). 1977. Water, Wastes and Health in Hot Climates. New York: John Wiley.

Fediore, Ibrahima. 1984. "Les formes de participation paysanne à la mise-en-valeur des aménagements hydro-agricoles," Développement agricole et participation paysanne. Un example, la politique de l'eau en Afrique. Paris: CNRS-CEJC.

Fehr, W.R., ed. 1984. Genetic Contributions to Yield Gains of Five Major Crop Plants. (CSSA Special Publication Number 7.) Proceedings of a symposium sponsored by Division C-1 of the Crop Science Society of America, 2 December 1981, in Atlanta, Georgia. Madison, Wisconsin: Crop Science Society of America, American Society of Agronomy.

Festinger, Georges. 1977. La mise en valeur du casier pilote de Kaedi: situation sociologique de référence: la mise en oeuvre du changement et les perspectives d'évolution sociologiques. Paris: IRAM.

Fieloux, M. 1980. "A Socio-Economic Study of a Toucouler Village, Bow (Senegal)." Purdue University: Workshop on Sahelian Agriculture, May 1980. Lafayette, Inc.: Dept. of Agric. Econ., Purdue University.

Finney, Chris. 1984. "Least-cost Analysis and the O & M Problem," Water Resources Development, Vol. 2, no. 1.

Fisher, N.M. and Browning, G. 1979. "Some Effects of Irrigation and Plant Density on the Water Relations of High Density Coffee (Coffea arabica L.) in Kenya," Journal of Horticultural Science, vol. 54, no. 1, pp. 13-22.

Fitter, J.C. 1983. "Evaluation of the Organisational Structure of Management Systems of the National Irrigation Schemes in Kenya," DVWK Bulletin 8. German Association for Water Resources and Land Improvement. Verlag Paul Parey, Hamburg/Berlin.

Flavigny, Claude and René Cousin. 1982. "Le développement de la vallée: quelques problèmes-clés," Afrique Agricul-ture, No. 77, janvier 1982, pp. 25-28.

Flavigny, Claude and Rene Cousin. 1982. "OMVS: Beaucop d'antecedents mais pas de précédents," Afrique Agriculture, No. 77, janvier 1982, pp. 18-22.

Flavigny, Claude and Rene Cousin. 1982. "Projet hydro-agricoles: bilan et perspectives," Afrique Agriculture, No. 77, janvier 1982, pp. 22-25.

Fleuret, Patrick. 1985. "The Social Organization of Water Control in Taita Hills, Kenya," American Ethnologist, vol. 12, no. 1, pp. 103-118.

Focan, A. 1961. "Mise en Valeur Rationnelle du Paysage et des Sols du Rwanda-Burundi," Bulletin d'Information de l'INEAC, Vol. 10, pp. 91-105.

Fofana, Ba Sayon. 1976. Les problèmes d'aménagements dans la Vallée du fleuve Niger (Mali). Thèse, Université de Rouen.

Fofana, Mamadou. 1981. Le développement agricole et déficit céréalier au Mali. Thèse de troisième siècle, Faculté de Droit et Science Economique, Université de Montpellier, 282 pp.

Ford, Robert E. 1982. Subsistence Farming Systems in Semi-Arid Northern Yatenga (Upper Volta). Ph.D. Thesis, University of California, Riverside, 674 pp.

Forest, F. 1980. L'irrigation de complement à la portée de systèmes agricoles vivriers paysans utilisant la technologie biogaz-compost. Paris: CENECA, 17 pp.

Fortmann, L. and E. Roe. 1981. "Dam Groups in Botswana," Pastoral Network Paper No. 126, Agricultural Administration Unit, Overseas Development Institute, London.

Foster, S.S.D. 1978. "The Likelihood of Active Groundwater Recharge in the Botswana Kalahari". Journal of Hydrology, vol. 55, nos. 1/4, pp. 113-136.

Foth, H.D. and J.W. Schafer. 1980. Soil Geography and Land Use. John Wiley and Sons, New York.

Fournier, A. 1973. Manuel d'agriculture générale tropicale: Le sol. Yaoundé: Ministère de l'agriculture, 378 pp.

Fournier, F. 1963. "The Soils of Africa," pp. 221-248. In, UNESCO, A Review of the Natural Resources of the African Continent. New York: International Documents Service, UNESCO/Columbia Univ. Press.

Fournier, J.B. 1975. Palmeraie de Ouidah-Nord projet étude économique. Paris: SONADER, Porto Novo, Ministère de la Coopération/DDE, 88 pp.

Française, République, Ministère de la coopération. 1964. Techniques rurales en Afrique. Paris: Ministère de le Coopération.

Française, République, Ministère de l'agriculture. 1977. Techniques des barrages en aménagement rural. Paris, 325 pp.

Française, République, Ministère de la coopération. 1978. perspectives de production vivrières pour l'irrigation dans le Sahel. Paris: Ministère de la coopération.

Française, République, Ministère de la Coopération. 1979. Etude des charges recurrentes des aménagements hydroagricoles au Niger Analyse des Principaux Résultats Economiques. Paris Sedes (84 rue de Lille 75007), 155 pp.

Française, République, Ministère de la coopération. 1979. Quelques aspects de l'hydraulique des barrages. Paris: CIEH, 24 pp.

Française, République, Ministère de la coopération. 1980. La lutte contre le désertification dans les pays du Sahel. L'experience française. Paris: Ministère de la Cooperation, 73 pp.

Française, République, Ministère de la coopération. 1981. Dossier d'information sur les barrages du Sahel. Paris: Ministère de la Coopération, 41 pp.

Française, République, Ministère de rélations extérieures. 1982. Evaluation économique de l'aménagement de la rive gauche du fleuve Senegal. Rapport general. Paris: CCCE, 199 pp.

Française, République, Ministère des rélations extérieures. 1984. Memento de l'agronome. Techniques rurales en Afrique. Paris: Ministère des rélations extérieurs, 1604 pp.

France, Norbert Beyrand. L'aménagement des vallées des Volta et le développement de la République du Haute Volta. Ouagadougou: Ministère du Plan, 101 pp.

Francis, Paul. 1986. "Land Nationalisation and Rural Land Tneure in Southwest Nigeria," ILCA Bulletin, no. 24, pp. 2-7.

Franke, Richard W. and Barbara Chasin. 1980. Seeds of Famine. Totowa, N.J.: Allanheld, Osmun, 167 pp.

Franzel, Steven. 1979. An Interim Evaluation of Two Agricultural Production Projects in Senegal: The Economics of Rainfed and Irrigated Agriculture. (African Rural Economy Program Working Paper No. 28.) East Lansing, Michigan: Michigan State University.

Frasier, Gary W. 1984. "Water Harvesting, Including New Techniques of Maximizing Rainfall Use in Semiarid Areas," pp. 46-71. Davis, Ted J. (ed.) Proceedings of the Fourth Agriculture Sector Symposium. Washington, D.C.: The World Bank.

Fresson, Sylviane. 1978. La participation paysanne sur les périmètres villageois d'irrigation par pompage de la zone de Matam au Senegal. Paris: OCDE, 65 pp.

Fresson, Sylviane. 1978. "Public Participation in Village Level Irrigation Perimeters in the Matam Region of Senegal," Experiences in Rural Development, Occ. Paper No. 4. Paris: OECD Development Paper (CD/R 78 12)

Fresson, Sylviane. 1978. Village Participation in Pump Irrigation Areas in the Matam Zone in Senegal. Paris: OECD, 130 pp.

Fresson, Sylviane. 1980. La lutte contre la desertification dans les pays du Sahel. L'Experience Française. Paris: Ministère de la coopération, 73 pp.

Fresson, Sylviane, et al. 1985. Evaluation de l'office du Niger (Mali). Paris: Ministère des Relations Exterieures Cooperation et Développement.

Funel, Jean-Marie. 1976. Le développement régionale et sa problématique études à travers l'expérience de Tahoua. Paris: Ministère de la Coopération, Serie Méthodologie de Planification, No. 9, 336 pp.

Funel, Jean Marie. 1978. Les systèmes ruraux saheliens Contribution et annexe a Essai de définition d'une stra-tegie anti-sécheresse dans le sahel de l'Afrique de l'Ouest. Paris: SCET, SEDES, 439 pp.

Funel, Jean-Marie and Guy Laucoin. 1981. Développement en zones arides; Politiques d'aménagement hydro-agricole. Paris: Agence de Coopération Culturelle et Technique, 212 pp.

Funel, J.M. and G. Laucoin. 1980. Politiques d'aménagement agricole. Paris, France: Presses Universitaires de France.

Funel, Jean-Marie, et al. 1984. La Somalac a Madagascar. Production, Organisation et Developpement, Davis: Republique Francaise, 315 pp.

Funel, Lemelle and M. Acheriaux. 1980. Analyse économique d'une opération d'aménagement hydro-agricoles. Paris: Ministère de la Coopération, 126 pp.

Gadelle, F. 1967. Rapport de mission en Haute-Volta 4 au 16 Décembre, 1967. Considération générales sur les aménagements hydro-agricoles. Paris: Ministère de la Coopération, 56 pp.

Gadelle. 1968. Rapport de mission en Haute-Volta. Considerations generales sur les améngagements hydro-agricoles. Paris: Secretariat d'Etat pour les Affaires Etrangères.

Gadelle, M. 1969. Les étapes d'un aménagement hydro-agricole dans les pays en voie de développement. Paris: SEAE, 78 pp.

Gaitskell, Arthur. 1959. Gezira: A Story of Development in the Sudan. London: Faber and Faber.

Galabi, Mohamed Adam. 1984. "The New Halfa Rehabilitation," pp. 71-72. In, O. Fadl and C. Bailey (eds.) Water Distribution in Sudanese Irrigated Agriculture: Productivity and Equity. Wad Medani, Sudan: University of Gezira.

Gallais, Jean. 1958. "La vie saisonnière au sud du lac Débo," Les Cahiers d'Outre-Mer, Vol. II, pp. 117-141.

Gallais, Jean. 1965. "Le paysan Dogon (République du Mali)," Les Cahiers d'Outre Mer, No. 70, pp. 123-143.

Gallais, Jean. 1967. Le delta interieur du Niger - Etude de géographie régionale. Dakar: IFAN, 2 Volumes.

Gallais, Jean. 1972. "Essai sur la situation actuelle des relations entre pasteurs et paysans dans Sahel ouest-africain," pp. 301-313. Etudes de géographie tropicals offertes à Pierre Gourou. Paris/The Hague: Mouton.

Gallais, Jean. 1975. Pasteurs et Paysans du Gourma. Paris: Editions du Centre National de la Recherche Scientifique, 239 pp.

Gallais, Jean. 1975. "Traditions pastorales et développement: problèmes actuels dans la region de Mopti (Mali)," pp. 354-366. In: Monod, Theodore (ed.) Pastoralism in Tropical Africa. London: Oxford University Press.

Gallais, Jean. 1976. "Options prises en ign··ées dans les aménagements hydro-agricoles en Afrique Sahelienne," Cahiers Géographique de Rouen, No. 6, pp. 77-95.

Gallais, J. and A.H. Sidikou. 1978. Traditional Strategies, Modern Decision-Making and Management of Natural Resources in the Sudan-Sahel. UNESCO, Management of natural resources in Africa: traditional strategies and modern decision-making. MAB Technical Note 9. Paris: UNESCO.

Gannet, Flemming and Carpenter, Inc. (n.d.) Assessment of Environmental Effects of Proposed Developments in the Senegal River Basin. Synthesis: Final Report. Harrisburg, PA in association with Crgatec Société Africaine d'Etudes Techniques, Dakar, Sénégal for OMVS, 195 pp.

Gans, Gert De. Kaputir Irrigation Scheme (Turkana District).

Gans, Gert De. Loyopat Irrigation Scheme (Turkana District).

Garces, C., Lazaro, R. C. and Akhand, N. A. 1986. "Methodologies to Evaluate the Performance of Irrigation Systems in Bangladesh," pp. 142-168. In, Bangladesh Agricultural Research Council, Methodologies to Evaluate the Performance of Irrigation Systems. Dhaka: Bangladesh Agricultural and Research Council and Winrock International Institute for Agriculture Development.

Garibal, R. 1970. Cours d'hydraulique agricole a l'usage des lycées agricoles de Madagascar. Tananarive: BDPA, 2 Tomes.

Gasse, V. 1971. Les Régimes Foncières Africains et Malagaches--Evaluation Depuis l'Independance. Paris: LGDJ.

Gathee, J.W. 1982. "Farming Systems Economics: Fitting Research to Farmers' Conditions," pp. 136-140. In, Keswani, C.L. and Ndunguru, B. (eds.) Intercropping. Ottawa: International Development Research Centre.

Gazzo, Yves. 1985. "Irrigation et participation paysanne au Kenya, exemple du projet de Bura," pp. 376-380. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Déeloppement agricole et participation paysanne. Paris: Economica.

Geist, Judith K. 1981. Coastal Agrarian Underdevelopment and Regional Imbalance in Kenya. Ph.D. Thesis, University of California, Berkeley, 784 pp.

Gellar, Sheldon. 1981. Planning, Management and Participatory Development: Issues in Irrigation Projects: A Select Annotated Bibliography. Club du Sahel/CILSS.

Gellar, Sheldon. 1982. Development by and for the People. Paris: OECD, Club du sahel, 74 pp.

Gellar, Sheldon. 1982. Senegal. Boulder, Colorado: Westview Press, 145 pp.

Geny, P., Lafarge, and Van Aubel. 1964. Mission de reconnaisance préliminaires à l'étude de la vallée du Mandoul. 2 Vol. Paris: BDPA.

GERSAR. 1980. Inventaire préliminaire des sites de petits aménagements hydro-agricoles au Togo. Rapport de la mission d'experts du 15.01 au 1.02, 1980. 2 Volumes. Paris: Ministère de la Coopération. Ministère du Plan, Lomé.

Gershenberg, I. 1971. "Customary Land Tenure as a Constraint on Agricultural Development--A Re-Evaluation," East Africa Journal of Rural Development, Vol. 4, No. 1.

Gethin-Jones, G.H. and R.M. Scott. 1959. "Soil Map of Kenya, 1:3,000,000." Atlas of Kenya, Nairobi.

Ghana. 1980. "Ghana: Upper Region Agricultural Development Project," Grove, A. T. and Adams, W. M. (eds.), Irrigation in Africa; Problems and Problem Solving Cambridge, England: African Studies Centre, University of Cambridge.

Ghodake and Hardaker. 1981. Whole Farm Modeling for Assessment of Dryland Technology. India: ICRISAT.

Gibb, Alexander and Partners. 1956. Kenya Nile Basin Water Resources Survey 1954-56. London: Alexander Gibb & Partners.

Gichuki, Francise. 1986. "An Analysis of Technical Manpower Needs and Training Activities in Support of Small-Scale Irrigation Development," pp. 94-108. In, Coward, E.W., Jr. et al., Watering the Shamba. Ithaca, New York: Cornell University.

Giglioli, E.G. 1965. "Staff Organisation and Tenant Discipline on an Irrigated Land Settlement," East African Agriculture and Forest Journal, Vol. 30, pp. 202-5.

Gil, N. 1979. Watershed Development with Special Reference to Soil and Water Conservation. FAO Soils Bulletin 44. Rome: FAO, 257 pp.

Gilbert, E.H., D.W. Norman and F.E. Winch. 1980. Les recherches sur les systèmes d'exploitation agricole: une evaluation critique. Développement Rural Cahier MSU No. 6. East Lansing, Michigan: Dept. of Agric. Economics, Michigan State University.

Gilet, N. 1973. "Caraterisation et mise-en-valeur des petites vallées ou bas-fonds pour l'agriculture irriguée," L'Agronomie Tropicale, Vol. 28, No. 11 (November 1973).

Gill, M.A. 1974. "Hydrological Characteristics of the Sokoto-Rima Basin," Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria. Savanna, Vol. 3, No. 1, 1974, pp. 61-76, 10 ref.

Gill, M.A. 1981. Development of Water Resources in the Sokoto, West African Technical Review, June 1981, pp. 99, 103.

Gillet, N. 1973. "Characterization and Development of Small Valleys or Valley Bottoms for Irrigated Agriculture," Agronomie Tropicale, 28, 11, pp. 1089-1093.

Gillet, M. 1981. Service de la recherche appliquée, cultures irriguées: Rapport de Mission du 6 au 16 Avril. Paris: IRAT, (Maradi Rural Development Project).

Gillham, F.E.M. 1972. "The Relationship Between Insect Pests and Cotton Production in Central Africa." In: Farvar, M. T. and John P. Milton, The Careless Technology; Ecology and International Development. Garden City: The Natural History Press.

Girard, G. and J.A. Rodier. 1979. "Application de modèles mathématiques deterministes à l'étude des crues de l'écoutement annuel - zones saheliennes," International Association of Scientific Hydrology, 1979, The Hydrology of Areas of Low Precipitation, Proceedings of the Canberra Symposium, December 1979, IAHS-AISH Publication 128, pp. 65-78.

Girardier, J.P. and M. Vergnet. 1976. "La pompe solaire et le développement rural integré," La Technologie Appropriée: Problèmes et Promesses. Paris: OECD, 391 pp.

Gischler, C. 1979. Water Resources in the Arab Middle East and North Africa. England: Menas Ltd.

Gitelson, S.A. 1971. "The Mubuku Irrigation Scheme: A Case Study," East African Journal, Vol. 8, No. 5, pp. 16-25.

Gitelson, S.A. 1975. Multilateral Aid for National Development and Self-reliance. A Case Study of the UNDP in Uganda and Tanzania. Kampala, Uganda: East African Literature Bureau.

Gitonga, Samuel M. 1985. Bura Irrigation and Settlement Project, Kenya. Paper presented to the Informal Meeting on Irrigation in Anglophone Africa. 24-28 June, 1985. Rome: FAO, 47 pp.

Glaeser, Bernhard. 1984. Ecodevelopment in Tanzania. Amsterdam: Mouton.

Gleizes, M. 1965. Projet d'aménagement hydro-agricole de la plaine de Boghe et note pour la pour suite de l'aménagement de la plaine de Boghe par SOGETHA. Paris: Ministère de la Coopération, 24 pp.

Godana, Bonaya A. 1985. Africa's Shared Water Resources. London: Frances Pinter, 370 pp.

Godinho Gouvei, D.H. and A.L. Azevedo. 1948. Cartas dos solos de Mozambique (1:6,000,000).

Goering, T. James. 1979. Tropical Root Crops and Rural Development. (World Bank Staff Working Paper No. 324.) Washington, D. C.: The World Bank.

Goffinet, R. 1964. Essai d'Adaptation du Cafeier Robusta avec Irrigation par Aspersion a Kaniama. (Serie Technique No. 71.) Bruxelles: INEAC.

Goldsmith, E. and Hildyard, N. 1984. The Social and Environmental Effects of Large Dams, vol. 1, Overview. Camelford, Cornwall: Wadebridge Ecological Centre, 400 pp.

Goldsmith, E. and Hildyard, N. (eds.) 1986. The Social and Environmental Effects of Large Dams, vol. 2, Case Studies. Camelford, Cornwall: Wadebridge Ecological Centre, 331 pp.

Goll, P.H. 1982. "Seasonal Changes in the Distribution of Biomphalaria Sudanica (Martens) in Lake Zwai, Ethiopia," Annals of Tropical Medicine and Parasitology, 76.2, pp. 159-164.

Gontard, et al. 1976. "Les priorités de recherches pour le développement à moyen et a long terme du Sahel. Un essai Bibliographique," Geneve-Afrique Vol. xiv, 1, 2, 1975.

Goody, Jack. 1980. "Rice-Burning and the Green Revolution in Northern Ghana," Journal of Development Studies. Vol. 16, No. 2, pp. 136-155.

Gourou, Pierre. 1962. L'avenir du monde tropical. Le Delta interieur du Niger. Paris: CCCE, 13 pp.

Grainger, Alan. 1982. Desertification. How people make deserts, how people can stop and why they don't. London: International Institute for Environment and Development, 94 pp.

Grandet, C. 1958. "La vie rurale dans le cercle de Goundam," Les Cahiers d'Outre-Mer, Vol. II, pp. 25-46.

Gras, R. et-al. 1978. Les barrages souterrains. Paris: Ministère de la coopération, BCEOM, 135 pp.

Gray, Clive and André Martens. 1982. "The Political Economy of the 'Recurrent Cost Problem' in the West African Sahel." Development Discussion Paper No. 128. Cambridge, MA: Harvard Institute for International Development.

Gray, Clive and André Martens. 1980. Recurrent Costs of Development Programs in the Countries of the Sahel. Paris: Club du Sahel/CILSS Working Group on Recurrent Costs, Paris.

Gray, R.F. 1959. The Sonjo: An Irrigation-Based Society of East Africa. Ph.D. Thesis University of Chicago.

Gray, R. 1963. The Sonjo of Tanganyika: An Anthropological Study of an Irrigation Based Society. London: Oxford University Press.

GRDR. 1980. Recherche et réalisations sur les techniques d'exhaure, animale en vue de leur implantation en zone Sahelienne. Paris: GRDR, 6 pp.

GRDR. 1980. Dossier exhaure animale et manuelle. Paris: GRDR.

Greathead, D.J. and J.K. Waage. 1983. Opportunities for Biological Control of Agricultural Pests in Developing Countries. (World Bank Technical Paper Number II.) Washington, D. C.: The World Bank.

Greenshields, Bruce L. and Bellamy, Margot A. (eds.) 1983. Rural Development: Growth and Inequity. I.A.A.E. Occasional Paper No. 3. Aldershot, England: Gower Pub. Co. for the International Association of Agricultural Economists.

Greigert, J. 1968. Les eaux souterraines de la République du Niger. 2 Volumes. Niamey: BRGM.

Gresillon, J.M. 1975. "Quelques problèmes, posés par la réalisation et l'entretien des petits barrages en terre en Afrique occidentale," Bulletin de Liaison du CIEH" No. 23, Nov. 75, pp. 2-17.

Gresillon, et al. 1979. Quelques aspects de l'hydraulique des Barrages. Paris: Minstère de le Coopération, 75 pp.

Gresillon-Herter. 1979. Quelques aspects de la tenue des ouvrages en terre et leur amelioration. Paris: Ministère de la Coopération, 57 pp.

Gresillon, J.M., and T. Metro. 1979. "Quelques corrélations entre randeurs mesurées sur les petits barrages en terre en Haute Volta: Consequences hydroliques," Bulletin technique de l'EIER, No. 4, July, pp. 1-13.

Gresillon-Traore. 1981. "Etude des couts moyens des barrages en fonction de leur taille," Bulletin de liaison du CIEH. No. 46. pp. 17-30.

Griffin, Richard E., George H. Hargreaves, Gary Z. Watters, R. Kern Stutler and LeRoy Salazar. Pumps and Water Lifters for Irrigation. Handbook No. 3. Logan, Utah: Agricultural and Irrigation Engineering Department, Utah State University. Utah State University, Logan, Utah. 158 pp. University, Logan, Utah. 158 pp.

Griffiths, J.F. (ed.). 1972. "Climates of Africa," World Survey of Climatology, Vol. 10. Amsterdam: Elsevier Publishing Company.

Griffiths, W.J. 1982. "Dadin Kowa, the Upper Benue and the TVA." Unpublished paper presented at a workshop for the Upper Benue River Basin Authority.

Griffiths, W.J. 1983. "Springs of Irrigation--Sudan and Nigeria." Paper presented for International Conference: Développement agricole et participation paysanne Un example: les politiques de l'eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Griffiths, W.J. 1984. "Madness of Fowl, Marriage with Cat?" pp. 4-13. In, Irrigation in Tropical Africa, Problems and Problem Solving. Cambridge, England; African Studies Centre, Univ. of Cambridge.

Grimsdell, J.J.R. and R.H.V. Bell. 1967. "The Bangweulu Basin of Zambia," Proceedings of the Symposium on the Okovango Delta and its Future Utilisation. Gaberone, Botswana, August 30th - September 22nd 1976. Gaberone: Botswana Society, pp. 257-262.

Grist, D.H. 1975. Rice. Longman Tropical Agriculture Series. London.

Grove, A.T. 1970. Africa South of the Sahara. London: Oxford University Press, 280 pp.

Grove, A.T. (ed.) 1985. The Niger and its Neighbours. Rotterdam: A. A. Balkema, 331 pp.

Grove, A.T. 1985. "The river people," pp. 143-176. In, Grove, A.T. (ed.) The Niger and its Neighbours. Rotterdam: A. A. Balkema.

Grove, J.M., et al. 1982. "Irrigation in the Volta Delta, Ghana." In, H.G. Mensching and V. Haarman (eds.) Problems of the Management of Irrigated Land in Areas of Traditional and Modern Cultivation Hamburg: IGU Working Group on Resource Management in Drylands.

Guerin, Jean-Luc. 1972. Contribution à l'élaboration d'un schéma directeur, d'aménagement des eaux du Togo. Rapport d'une mission FAC effectuée 22 janvier au 1er février 1979. Paris: Ministère de la Coopération, 122 pp.

Gueye, Mour and Charles Renard. 1982. "Comparison de Deux Cultivars de Riz (SE 302 G et IR442) Soumis à la Sécheresse en Debut de Floraison," Agronomie Tropicale, Vol. 37, No. 1, pp. 81-88.

Guggenheim, Hans and Rosalie Fanale. 1976. Shared Technology: a Project for Water Storage and Irrigation in Dogon Villages. Dakar: ENDA; London: IAI, 16 pp.

Guillaume, M. 1959. Rapport d'une mission d'étude de leur possibilitiés d'extension. Khartoum: Mission d'étude des aménagements du Niger, 3 Volumes, 327 pp.

Guillaume, M. 1960. "Les aménagements hydro-agricoles et de décrue dans la vallée du Niger," Agronomie Tropicale, Vol. 15, No. 1-4.

Guillaume, M. 1961. Rapport au gouvernment du Mali sur les perspectives de développement des aménagements hydro-agricoles eu milieu rural traditionnel. Rome: FAO, 33 pp.

Guillobez, S. 1977. Etudes morphopédologiques: projet Bagré, Rapport Général (campagnes 75, 76, 77). Paris: IRAT, 89 pp.

Haddow, Paul S. 1980. "International Influences on Sectoral Development Strategies: The Case of Rural Water Provision in Kenya," pp. 157-206. In, Pinfold, Tom and Norcliffe, Glen (eds.) Development Planning in Kenya. Geographical Monographs, No. 9. Toronto: York University.

Hagin, J. and B. Tucker. 1982. Fertilization of Dryland and Irrigated Soils. Germany: Springer-Verlag Berlin Heidelberg. (Advanced Series in Agricultural Sciences 12.)

Haissman, I. 1970. Skilled Manpower Planning for Irrigation Projects in Developing Countries. Ph.D. Thesis, Univ. of California, Berkeley.

Hall, A.E., G.H. Cannell and H.W. Lawton, (eds.) 1979. Agriculture in Semi-Arid Environments (Ecological Studies, Vol. 34). Heidelberg: Springer-Verlag Berlin.

Hall, T.D. 1940. "Soil Fertility in Southern Africa." Journal of the Africa Society 39:1960-1969.

Hamilton, J.M. 1978. "Wind that Brings Water," Maryknoll, vol. 72, no. 7, pp. 9-10.

Hanger, Jane and Jon Moris. 1973. "Women and the Household Economy," pp. 209-244. In, Chambers R. and Moris, J. (eds.) Mwea. An Irrigated Rice Settlement in Kenya. IFO Institute Afrika Studien Nr. 83. Munich: Weltforum Verlag.

Harbeson, J.W. 1980. "Land and Rural Development in Independent Zimbabwe: A Preliminary Analysis," Land Tenure Center Newsletter, No. 69.

Harbeson, J.W. 1975. "Afar Pastoralists and Ethiopian Rural Development," Rural Africana, No. 28, pp. 71-86.

Hargreaves, G. Leo, George H. Harvgreaves, and J. Paul Riley. 1985. "Irrigation Water Requirements for Senegal River Basin," Journal of Irrigation and Drainage Engineering, vol. 111, no. 2, pp. 265-275.

Harlan, Jack R. 1975. Crops and Man. Madison, Wisconsin: American Society of Agronomy and Crop Science Society of America, 295 pp.

Harlan, Jack and Jean Pasquereau. 1968. "Décrue agriculture in Mali," Economic Botany, pp. 70-74.

Harris, David R. (ed.) 1980. Human Ecology in Savanna Environments. New York: Academic Press.

Harris, R. 1983. "Zimbabwe" African Water and Sewage, June 1983, Vol. 2, No. 2. Redhill, U. K., pp. 18-26.

Harriss, Barbara 1982. Agricultural Marketing in the Semi-Arid Tropics of West Africa. Devleopment Studies, Occasional Paper No. 17 (March). Norwich, England: Overseas Development Group, University of East Anglia, 133 pp.

Hartmann, R. and M. Gandah. 1982. "Hydrodynamic Characterization of a Sand Dune Soil in Niger." Modedelingen van de Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent, 47(4):1195-1204.

Hartog, T. 1979. "La vallée du Kou: Un exemple d'intervention planifiée et d'encadrement paysan dans l'ouest Voltaique," Maitrise de l'espace agraire et développement en Afrique Tropical. Paris: Editions de l'Office de la Recherche Scientifique et Technique Outre-Mer, pp. 301-306.

Haswell, Margaret. 1985 (2nd. ed.). Energy for Subsistence. London: Macmillan, 130 pp.

Hautaluoma, Jacob E. et al. 1980. Development Process for Improving Irrigation Water Management on Farms. Project Implementation Manual. Water Management Technical Report No. 65 D. Fort Collins, Colo.: Colorado State University, 111 pp.

Haute Volta, République du. Alimentation complémentaire en eau à partir de la Volta Noire: Etude préliminaire. Paris: SEAE-SEURECA.

Haute Volta, République du. Barrage de Poesse. Paris: BDPA. 20 pp.

Haute Volta, République du. 1961. Pré-étude économique et sociale de sites de Barrages. Paris: Compagnie Générale d'études et recherches pour l'Afrique (COGERAF), 2 Volumes.

Haute Volta, République du, SCET. 1973. Programme d'hydraulique au Sahel. Paris: SCET, December 1973, 3 Volumes.

Haute Volta, République du, Ministère de l'agriculture et de l'élevage. 1969. Section expérimentale d'hydraulique agricole de Montedo: Rapport de fin de Campagne 1968-1969. Paris: IRAT.

Hautier, J. 1962. Rapport de pre-étude pour la réalisation des études socio-économiques interessant la zone des cuvettes lacustres et ouadi du lac Tchad. Paris: BDPA, 77 pp.

Hautier, J. 1963. La commercialisation traditionelle du blé dans la zone des cuvettes lacustres et ouadi du lac Tchad. Paris: BDPA, 1963, 76 pp.

Hawksworth, D.L. (ed). 1984. Advancing Agricultural Production in Africa. Farnham Royal, Slough, England: Commonwealth Agricultural Bureaux, 454 pp.

Hazell, J. R. Temple 1984. "Distribution, Availability and Use of Groundwater for Irrigation in the Northern Zone, B.S.A.D.P.," pp. 8-18. In, Bauchi State Agricultural Development Programme, Second Fadama Seminar (6-8 March, 1984). Azare, Nigeria: Bauchi State Agricultural Development Programme, Northern Zone.

Hazlewood, Arthur, and Ian Livingstone. 1978. "Complementarity and Competitiveness of Large and Small Irrigated Farming: A Tanzanian Example." Oxford Bulletin of Economics and Statistics, Vol 40, August 1978.

Hazlewood, Arthur D. and I. Livingstone. 1982. Irrigation Economics in Poor Countries, Illustrated by the Usangu Plains of Tanzania. Oxford, U. K.: Pergamon Press.

Heathcote, R. L. 1983. The Arid Lands: Their Use and Abuse. London: Longmans.

Heindl, L. A. 1974. Hidden Waters in Arid Land. (Report of a workshop on Groundwater Research Needs in Arid and Semi-arid Zones held in Paris, France, 25th November). Ottawa: International Development Research Centre.

Heinritz, G. 1978. "Social Geographic Problems in the Khasm-El-Girba Project, Sudan," Land Reform, Land Settlement and Co-operatives, No. 2, pp. 25-36.

Heinritz, G. 1980. "The Rahad Scheme. A New Irrigation Project in the Sudan Republic." Zeitschrift fur Wirtschafts-geographie, Vol. 24, No. 3, 1980, pp. 81-87, (in German).

Hekstra, P. Dec. 1983. Prospects for Small-Scale Irrigation Development in East Africa. An Inventory made in Burundi-Kenya-Malawi-Tanzania Uganda. Land and Water Development Division, FAO, Rome.

Henin, S. 1977. Cours de physique du sol. L'eau et le sol, les propriétés mécaniques, la valeur et le sol. Paris: ORSTOM, 222 pp.

Henricksen, B.L. and J.W. Durkin. 1986. "Growing Period and Drought Early Warning in Africa Using Satellite Data," International Journal of Remote Sensing, vol. 7, no. 11, pp. 1583-1608.

Henry, Jean C. 1979. Present and Future Irrigated Agriculture in the Shebelle and Juba River Basins.

Hewitt, W. H. 1977. Land Resources Appraisal of the Gambia River Basin." New York: UNDP (mimeo.).

Heyer, Judith et al. (eds.) 1981. Rural Development in Tropical Africa. New York: St. Martin's Press, 375 pp.

Higgins, G.M, D.M. Ramsay, and R.A. Pullan. 1960. A Report on the Climate, Soils and Vegetation of the Niger Trough. Samaru, Zaria: Ministry of Agriculture, (with map).

Higgins, G. M. et al. 1981. "Africa's Agricultural Potential," Ceres 14(5), pp. 13-26.

Hill, M. N., J. A. Chandler, and R. B. Highton. 1977. "A Comparison of Mosquito Problems in Irrigated and Non-Irrigated Areas of the Kano Plains, Nyanza Province, Kenya," pp. 307-316. In, B. Worthington (ed.), Arid Land Irrigation in Developing Countries. London: Pergamon Press.

Hillel, Daniel. 1977. Computer Simulation of Soil-water Dynamics. Ottowa, CRDI, 214 pp.

Hillmann, F. 1980. "Water Harvesting in Turkana District, Kenya," ODI Pastoral Development Network Paper 10d. London: Overseas Development Institute.

Hlavek, Robert and Jean Dupuis. 1981. Hydraulique villageoisse et développement rural dans le Sahel. Rapport technique et rapport de synthèse. Paris: Club du Sahel.

Hochet, Anne-Marie. 1975. La femme Toucouleur dans la société rural actuelle en voie de mutation. These troisieme cycle. Paris: EPHE, 334 pp.

Hochet, J. 1972. Perspectives et exigences socio-économiques du développement de l'agriculture irrigué en République Islamique de Mauritanie (basse et moyenne vallée du Sénégal, bassin du Gorgol. Dakar: PNVD/FAO, 108 pp.

Hogg, Richard. 1983. "Irrigation Agriculture and Pastoral Development: A Lesson from Kenya." Development and Change, vo. 14, no. 4, pp. 477-592.

Hogg, Richard. 1985. "The Politics of Drought: The Pauperization of Isiolo Boran," Disasters, vol. 9, no. 1, pp. 39-43.

Hogg, Richard. 1986. "The New Pastoralism: Poverty and Dependency in Northern Kenya," Africa, vol. 56, no. 3, pp. 319-332.

Hogg, Richard, n.d. "The Socio-Economic Responses of Nomadic Pastoralists to Permanent Settlement and Irrigation Agriculture," unpublished Escor Research Scheme report (no. R.3674), 157 pp.

Hoore, J. 1964. Soil Map of Africa, Scale 1:5,000,000: Explanatory Monograph. Lagos, Nigeria.

Hopfen, H.J. 1969. Farm Implements for Arid and Tropical Regions. FAO Agricultural Development Paper, No. 91. Rome: FAO, 159 pp.

Hopkinson, E. G. and C. F. Beavington, (eds.). "Report of the Regional Workshop on Hydrogeology in Commonwealth Africa," Proceedings, Vol. 1, held in Lobatse, Botswana, 12-21 June 1979. London: Commonwealth Geological Liaison Office.

Horowitz, Michael. 1983. Niger: A Social and Institutional Profile. Washington, D.C.: USAID.

Horst, L. 1982. "Alternative Development Concepts in Potential Polder Areas," Polders of the World, Vol. 1. Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, Wageningen, Netherlands, pp. 320-329.

Horst, L. 1983. Irrigation Systems - Alternative Design Concepts. Irrigation Management Network Paper 7c. Overseas Development Institute, London, U.K.

Horst, Lucas. 1986. "Choice of Irrigation Structures," pp. 45-60. In, Hydraulics Research, Irrigation Design for Management, Asian Regional Symposium (16-18 February, 1987). Wallingford, England: Hydraulics Research.

Hoskins, Marilyn and Fred Weber. 1982. Evaluation of Lutheran World Relief Projects, Niger, (unpublished report). Niamey: Lutheran World Relief. 73 pp.

Hotes, Frederick L. 1983. "World Bank Irrigation Experiences," International Journal of Water Resources Development, Vol. 1, No. 1, April 1983, (also as ODI Irrigation Management Network Paper 9d, April 1984).

Houghton, J. T. (ed.). 1984. The Global Climate. London: Cambridge University Press.

Howell, John (ed.). 1985. Recurrent Costs and Agricultural Development. London: Overseas Development Institute, 223 pp.

Hoyle, Steve. 1977. "The Khashm-El-Girba Agricultural Scheme: An Example of an Attempt to Settle Nomads," pp. 116-131. In, O'Keefe, P. and Wisner, B. (eds.) Landuse and Development. African Environment Special Report, no. 5. London: International African Institute.

Huetz de Lemps, Alain. 1974. Types d'agriculture commerciale. Talence: Centre d'Etudes de Géographie Tropicale, 237 pp.

Hughes, Charles C. and John M. Hunter. 1970. "Diseases and 'Development' in Africa," pp. 443-493. Social Science and Medicine, Vol. 3. Pergamon Press.

Hughes, F. M. 1984. "Fuelwood: A Forgotten Dimension of Irrigation Planning," pp. 50-66. In, W. Adams and A. T. Grove (eds.) Irrigation in Tropical Africa, Problems and Problem Solving. Cambridge, England: African Studies Centre, Cambridge University.

Humpal, Donald S., Albert Sollod, Fred Weber, and Eric B. Shearer. 1983. Food and Agriculture Sector Assessment, Mauritania--Analysis of Crops, Livestock and Forestry and Environment. Washington, D.C.: Development Alternatives, Inc. and Research Triangle Institute.

Humpal, Donald S. and Eric B. Shearer. 1982. Food and Agriculture Sector Assistance Options in Mauritania. Washington, D.C.: Development Alternatives, Inc. and Research Triangle Institute.

Humphreys, Charles P. 1979. "Data on Costs of Ivorian Rice Production," Stanford University: Food Research Institute, Stanford.

Humphreys, Charles P. 1981. "Rice Production in the Ivory Coast." In: Pearson et al, Rice in West Africa; Policy and Economics. Stanford: Stanford University Press.

Humphreys, Charles P. and Scott R. Pearson, 1980. "Choice of Technique in Sahelian Rice Production," Food Research Institute Studies, Vol. 17, No. 3 (1979-80), pp. 235-277.

Hunter, John. 1982. Zones d'exploration pour les terres neuves du Sahel. Vol. 1, Textes et tableaux. Paris: Club du Sahel/CILSS, 80 pp.

Hunting Survey Corporation. 1963. Agricultural and Water Survey in Somali Republic. Toronto: Hunting Survey Corporation.

Hunting Technical Services et al. 1981. National and Shire Irrigation Study. Final National Report. Hunting Technical Services Ltd. with Sir M. MacDonald and Partners and Ministry of Agriculture, Malawi, 241 pp.

Hurault, J. 1967. L'érosion regressive dans les régions tropicales humides et la genèse des inselbergs granitiques. Paris: IGN, 68 pp.

Hutcheon, W. V., R. W. Smith, and E. J. A. Asomaning. 1973. "Effect of Irrigation on the Yield and Physiological Behaviour of Mature Amelonado Cocoa in Ghana," Tropical Agriculture, 50, 4, pp. 261-272.

Hutton, S.M. and Dincer, T. 1981. "Using Landsat Imagery to Study the Okavango Swamp, Botswana," pp. 512-519. In, Deutsch, Morris et al. (eds). Satellite Hydrology. Minneapolis: American Water Resources Association.

Hydraulics Research. 1986. Irrigation Design for Management, Asian Regional Symposium (16-18 February 1987). Wallingford, England: Hydraulics Research.

Ibrahim, A.M. 1984. "Concepts of Design and Practice for Irrigation Distribution systems in Sudan," pp. 105-116. In, O. Fadl and C. Bailey (eds.) Water Distribution in Sudanese Irrigated Agriculture: Productivity and Equity. Wad Medani, Sudan: University of Gezira.

ICRISAT. 1979. "Agroclimatological Research Needs in the Semi-Arid Tropics," International Crops Research in the Semi-Arid Tropics. Patancheru, Hyderabad, Andhra Pradesh, India.

ICRISAT. 1980. "Climatic Classification," International Crops Research in the Semi-Arid Tropics. Patancheru, Hyberabad, Andhra Pradesh, India.

ICRISAT. 1980. Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. Patancheru, India: ICRISAT.

ILACO, 1981. Compendium for Agricultural Development in the Tropics and Subtropics. Amsterdam: Elsevier Scientific Publishing Company).

Independent Commission on International Humanitarian Issues. 1985. Famine: A Man-Made Disaster? New York: Vintage Books, Random House, 160 pp.

Institut National pour l'Etude Agronomique du Congo Belge. 1959. "Station d'Essais de Lubarika," Rapport Annuel Pour l'Exercice 1958, pp. 367-375. Bruxelles: INEAC.

Institut National pour l'Etude Agronomique du Congo Belge. 1960. Le Paysannat de la Plaine de la Ruzizi. Yangambi: INEAC.

Interafrican Committee for Hydraulic Studies. 1977. Catalog du Centre de Documentation, 2 Vols. Boston: G.K. Hall.

Interafrican Committee for Hydraulic Studies. 1978. Savanna Regional Water Resources and Land Use, Vol. 1-7. Volume 7 water requirements. New York: TAMS Agricultural Development Group.

Intermediate Technology Development Group. 1969. The Introduction of Rainwater Catchment Tanks and Micro-Irrigation to Botswana. London: Intermediate Technology Development Group.

International Association of Scientific Hydrology. 1979. "The Hydrology of Areas of Low Precipitation," Proceedings of the Canberra Symposium, December 1979. IAHS-AISH Publication 128. Paris: IASH.

International Commission of Irrigation and Drainage. 1981. Irrigation and Drainage of the World, Vol. 1. International Commission of Irrigation and Drainage, New Delhi, India.

International Development Research Centre. 1981. Rural Water Supply in Developing Countries. Proceedings of a Workshop on Training held in Zomba, Malawi, 5-12 August, 1980. Ottawa: IDRC (IDRC-167e), 144 pp.

International Development Research Centre. 1982 Root Crops in Eastern Africa. Ottowa: IDRC with IITA and the Rwanda Government, 128 pp.

International Institute of Tropical Agriculture. 1983. Annual Report for 1982. Ibadan, Nigeria: IITA.

International Institute of Tropical Agriculture. 1984. Annual Report for 1983. Ibadan, Nigeria: IITA.

International Labor Office. 1972. Employment, Income and Equality: A Strategy for Increasing Productive Employment in Kenya. Geneva: ILO, 600 pp.

International Land Development Consultants. 1981. Agricultural Compendium for Rural Development in the Tropics and Subtropics. Amsterdam: Elsevier Scientific Publishing Company, commissioned by the Netherlands Ministry of Agriculture and Fisheries. The Hague.

International Rice Research Institute. 1982. A Plan for IRRI's Third Decade. Manila: International Rice Research Institute.

International Rice Research Institute. 1975. Major Research in Upland Rice. Manila: International Rice Research Institute.

International Rice Research Institute. 1980. Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics. Papers from an International Symposium sponsored by Cornell University and IRRI, Philippines, June 1979. Manila: International Rice Research Institute.

International Rice Research Institute. 1983. Research Highlights for 1982. Manila: International Rice Research Institute.

International Service for National Agricultural Research. 1982. La Recherche Agronomique en Côte d'Ivoire. The Hague: International Service for National Agricultural Research.

International Service for National Agricultural Research. 1983. Le Recherche Agronomique et Zootechnique, Haute-Volta. The Hague: International Service for National Agricultural Research.

IRAT. 1969. Synthèse et résultats 1968 de l'IRAT au Sénégal et sur la rive mauritanienne du fleuve Sénégal. Paris: IRAT, 166 pp.

IRAT. 1971. Station expérimentale d'hydraulique agricole de Tarna. Bilan de 7 années d'expérimentation 1963/1970. Paris: IRAT, 54 pp.

Irrinews. 1980. Focus on Irrigation in Sudan. Irrinews, Ottawa, Canada, International Irrigation Information Center, No. 20, pp. 1-2.

ISEA. 1. Vallée du Souro. Problèmes humains (rapport préliminaire). 2. Carte ethniques et cartes de Dedougou, Ouahygoya, Yako, Nouna et Tougan. Bordeaux: ISEA, 103 pp.

Jackson, C. 1984. "Hausa Women and Agricultural Change on the Kano River Project, Nigeria," pp. 67-74. In, Adams, W.M. and Grove, A.T., (eds). Irrigation in Tropical Africa. Cambridge African Monographs, No. 3. Cambridge, England: African Studies Centre, Cambridge University.

Jackson, I. J. 1977. Climate, Water and Agriculture in the Tropics. London: Longmans.

Jacob, M. et al. 1963. Problèmes sociaux et économiques de l'aménagement des polders de Boi, Bol-Guini et Bol- Berim. Paris: BDPA. 2 Volumes, 213 pp, 256 pp.

Jacquot, M. 1978. "Varietal Improvement Programme for Pluvial Rice in Francophone Africa," pp. 117-130. In: Buddenhagen, I.W., and G.J. Persley, eds., Rice in Africa. London: Academic Press.

Jadin, P. and J. Snoeck. 1982. "Evolution du stock d'eau sous une cacaoyére - relation avec le climat," Proceed ings, 8th International Cocoa Research Conference. Lagos, Nigeria: Cocoa Producers' Alliance 127-131.

Jager, T. 1982. Soils of the Serengeti Woodlands, Tanzania. Agricultural Research Reports, No. 912.

Jahnke, Hans E. 1982. Livestock Production Systems and Livestock Development in Tropical Africa. Kiel: Kieler Wissenschaftsverlag Vauk.

Jamin, J. Y. 1981. Etude d'unités de production de paysans pratiquant la culture irriguée dans le cadre de la SAED. Richard Toll, Dakar: ISRA, 27 pp. Mimeo.

Jamne, M. 1965. Rapport de synthèse pour un développement integré du bassin du Niger dans la République du Mali. Paris: EDF, 418 pp.

Jatzold, R. and E. Baum. 1968. The Kilombero Valley. Characteristic features of the economic geography of a semi-humid East African flood plain and its margins. IFO Afrika Studien No. 28. Munchen: Weltforum Verlag.

Jaujay, Jean. 1982. Coopération pour le développement de L'Afrique Bulletin de Liaison du comité "Périmètre irri-gué". No. 1, Paris: Caisse Centrale de Coopération Economique, 7 pp.

Jaujay, Jean. 1982. Cooperation for the development of Africa. Liaison Bulletin of the "irrigated perimetres" Committee No. 2. Paris: Caisse Centrale de Coopération Economique.

Jaujay, Jean. 1983. Coopéaration pour le développement de l'Afrique. Bulletin de liaison du comité. "Périmètres irriques." No. 3. Paris: Caisse Centrale de Coopération Economique, 21 pp.

Jean, Suzanne. 1975. Les Jachères en Afrique tropicale. Paris: Institute d'Ethnologie-Mussée de l'Homme, 168 pp.

Jeanguyot, M. et al. 1981. Coop 17288. Action de la France en matière de développement vivrier en Afrique tropicale. Paris: Ministère de la Culture, 278 pp.

Jedrej, M.C. and Stremmelaar, G. 1971. "Guneid Sugar Scheme: a Sociological Consideration of Some Aspects of Conflict Between Management and Tenants," Sudan Notes and Records, vol. 52, pp. 71-78.

Jenkins, D. W. 1972. Bilharzia Defeats Development. Smithsonian Inst., Washington DC 200560, USA. Lakartidningen, Vol. 69, No. 23, 1972, pp. 2822-2827, in English.

Jewsbury, J.M. 1984. "Small Scale Irrigation Projects and their Implications for Health," pp. 41-56. In, M. J. Blackie (ed). African Regional Symposium on Small Holder Irrigation. Harare, Zimbabwe: University of Zimbabwe.

Johansson, D. and Stromquist, L. 1978. "Interpretation of Geomorphology and Vegetation of LANDSAT Satellite Images from Semiarid Central Tanzania," Geogr. Tidsskr. (Oslo), vol. 4.

Johnny, Michael, John Karima and Paul Richards, 1981. "Upland and Swamp Rice Farming in Sierra Leone: The Social Context of Technological Change". Africa, Vol. 51(2) pp. 596-620.

Johnstone, H. V. C. 1928. The Gezira Irrigation Scheme: Canalisation of the Gezira. Proceedings of the Institute of Civil Engineers, London, Vol. 227 (1928- 29), pp. 68.

Jones, Christine W. 1982. "Women's Labour Allocation and Irrigated Rice Production in North Cameroon," pp. 172-177. In, Greenshields, Bruce L. and Bellamy, Margot A. (eds). Rural Development. Growth and Inequity. Aldershot, England: Gower Pub. Co., for the International Association of Agricultural Economists.

Jones, Christine W. 1983. The Impact of the SEMRY I Irrigated Rice Production Project on the Organization of Production and Consumption at the Intra-household Leve. USAID Contract No. PTR-0096-00-2232-00, 112 pp.

Jones, Christine W. 1983. The Mobilization of Women's Labor for Cash Crop Production: A Game-Theoretic Approach. Ph.D. Thesis, Economics, Harvard University, 183 pp.

Jones, Christine W. 1986. "Intra-Household Bargaining in Response to the Introduction of New Crops: A Case Study from North Cameroon," pp. 105-123. In, Moock, Joyce L. (ed.) Understanding Africa's Rural Households and Farming Systems, Boulder: Westview Press.

Jones, K. R. 1981. Arid Zone Hydrology for Agricultural Development. FAO Irrigation and Drainage Paper 37. Rome: FAO, 271 pp., Annexes (96 pp.).

Jones, William. 1976. Planning and Economic Policy: Socialist Mali and Her Neighbors. Washington, D.C.: Three Continents Press.

Jonsson, J. 1977. Resource Guide: Data in Agriculture. Department of Agriculture, Zambia.

Joseph, Stephen and Stanley Scheyer. 1977. A Strategy for Health as a Component of the Sahel Development Program. Washington, D.C.: Family Health Care, Inc. for USAID (AID/afr-C-1138, w.o.8), 99 pp.

Jourdes, M. 1979. Rapport de la mission effectuée par l'OFERMAT auprès de la société d'aménagement d'exploitation des terres du delta (SAED) à St. Louis de Sénégal. Juin 1979. Paris: OFERMAT, Ministère de la Coopération, 50 pp.

Joyce, Charles L. (ed.) 1978. Towards a Rational U.S. Policy on River Basin Development in the Sahel. Proceedings of a Colloquium, March 31 - April 1, 1978. Washington, D.C.: Agency for International Development.

Joyce, S. J. and F. Beudot. 1977. Elements for a Bibliography of the Sahel Drought. Paris: OECD.

Junot, J. 1969. Cours d'hydraulique agricole à l'usage des collèges agricoles de Madagascar. Tananarive: BDPA, 47 pp.

Jurion, F. and J. Henry. 1969. Can Primitive Farming be Modernised? Publications de l'Institut National pour l'Etude Agronomique du Congo Belge (INEAC). République Démocratique du Congo (Zaire), Office Nationale de la Recherche et du Développement (ONRD). Published with the assistance of the Belgian Cooperative and Development Office (OCD). Translated from the French work by the same authors, De l'Agriculture itinerante à l'agriculture intensifiée, 1967. Brussels: INEAC, 457 pp.

Jurriens, R., A. F. Bottrall, et al. 1984. Evaluation of Irrigation Design - a Debate, Irrigation Management Network Paper 9b. London: Overseas Development Institute.

Kabore, F. and J. Durant. 1983. L'hydraulique villageoise dans les pays membres du CILSS. les couts recurrents. Sahel D (83) 209. Bonckerville, Québec: AGROVET, OCDE.

Kaiser Engineers Inc., Beyrard, N. 1965. "Etude de rentabilité des aménagements hydro-agricoles et évaluation en tant que projet à but multiples," Projet du fleuve Bandama. 4 Volumes. Abidjan: Kaiser Engineers, Inc.

Kalms, J.M and J. Imbernon. 1983. "Conditions of the water supply of upland rice: account of research methods at Bouaké, Ivory Coast." (In French). Agronomie Tropicale, 38(3):198-205.

Kaloga, B. 1968. Etude pédologique de la Haute-Volta, région centresud. (with map at 1:[illegible],000). Dakar-Hann: ORSTOM.

Kamarck, Andrew M. 1976. The Tropics and Economic Development. Baltimore: The Johns Hopkins University Press.

Kamuanga, M. 1981. Farm Level Study of the Rice Production System at the Office du Niger in Mali: An Economic Analysis. Ph.D. Dissertation, Michigan State University, East Lansing.

Kamuanga, M. and D.S.C. Spencer. 1981. Losses of Rice in West Africa: The Case of the Office du Niger in Mali. WARDA Occasional Paper No. 5. Monrovia, Liberia: WARDA.

Kang, B.T., J.M. Spain and G. Uehava. "Management of Low Activity Clay Aflisols and Ultisols." Paper presented at a symposium on low activity clay soils, American Society of Agronomy Meetings, Las Vegas, NV.

Karst, J. 1973. "Multiplier les barrages regulateurs dans les pays en voie de développement," Industries et Travaux d'Outre-Mer" 237, pp. 682-693.

Karst, J. 1984. "L'Afrique reste au fond sous-developpée dans le domaine des grands barrages," Industries et Travaux d'Outre-Mer. No. 244, mars 1974, pp. 94-199.

Karst, J. 1974. "L'Aménagement hydro-électrique et hydro-agricole de Koussou en Côte d'Ivoire," Industries et Travaux d'Outre Mer, No. 246, May 1974, pp. 456-461.

Katz, R.W. and M.H. Glantz. 1977. "Rainfall Statistics, Droughts and Desertification in the Sahel," pp. 81-102. Glantz, M. H. (ed.) Desertification: Environmental Degradation in and Around Arid Lands. Boulder, Colo.: Westview Press.

Kay, M. G. 1976. "Water Management Practices on a Sugar Estate in Somalia," ODI Workshop on Choices in Irrigation Management, Paper C2, Overseas Development Institute, London.

Kay, M. G. et al. 1985. "The Prospects for Small Scale Irrigation in Sub-Saharan Africa," Outlook on Agriculture, vol. 14, no. 3, pp. 115-121.

Kebzabo, Saleh. 1974. "Fleuve Sénégal: Horizons 1982- 2011," Jeune Afrique, No. 714, 14 September, 1974, pp. 58-59.

Keheimer, Norman. 1979. Irrigated agriculture in the Sahel. Sahel d (79) 39. Paris: Club du Sahel/ CILSS, 12 pp.

Keita, M. 1975. "L'intervention en milieu rural et capitalisme agraire dans la région de Tillaberi," L'Agriculture africaine et le capitalisme Samir Amir (ed.). Paris: Éditions Anthropos, pp. 185-232.

Keita, Modibo. 1977. "De la culture de décrue à la culture irriguée," Le Moniteur Africain, No. 757, aout, pp. 47- 58.

Keita, Moribadjan. 1983. "The Bakel Small Scale Irrigated Perimeters: An Economic Analysis of Agricultural Production," USAID: Dakar.

Keita, Therese. 1982. Problèmatique de l'intégration des femmes aux coopératives au Niger. Zimbabwe: Seminaire-Femmes et Développement Rurale en Afrique.

Keller, Jack, Raymond F. Meyer, Freddie J. Peterson, Thomas F. Weaver, and Gerald C. Wheelock. 1982. Project Review for Bakel Small Irrigated Perimeters. USAID Project No. 685-0208. Water Management Synthesis Report 9. Logan: Utah State University.

Keller, Jack. 1985. "Taking Advantage of Modern Irrigation in Developing Countries," Agribusiness Worldwide, March/April.

Keller, J., T.F. Weaver, J.S. Mayo. 1986. Design Guidance for Shebelli Water Management Project: Somalia. Water Management Synthesis, Report 49, Logan, Utah: Utah State University.

Keller, Jack et al., 1987. Design Guide for Shebelli Water Management Project, Somalia. Water Management Synthesis Report 49, Logan, Utah State University.

Kellerman, Casati. 1964. Note au sujet du projet d'aménagement hydroagricole de 30,000ha de cuvettes dans le delta du Sénégal rive gauche). Paris: Ministère de la Coopération, 5 pp.

Kenya National Irrigation Board. 1983. Provisional Operation Operation Procedures for the Water Distribution in the Block Irrigation System. (Prepared by M. Jurriens and L. Molenaar, May 1983). Wageningen, the Netherlands: International Institute for Land Reclamation and Improvement.

Kenya, Republic of. 1985. Bura Irrigation Settlement Project: Mid-Term Evaluation Report, 1984. Nairobi: Government Printers.

Kenyan-Dutch Evaluation Team (Slabbers, Tarda). 1983. Evaluation of Lower Tana Village Irrigation Programme (unpublished).

Khalil, H. M. M. 1970. "The Sudan Gezira Scheme: Some Institutional and Administrative Aspects," Journal of Administration Overseas, Vol. 9, No. 4, pp. 273-285.

Khalil, S. E. M. 1980. "A Socio-economic Assessment of Family Labour Supply in New Halfa Irrigated Scheme," Bulletin. Economic and Social Research Council, Sudan, No. 86.

Khider, Mahassin, and Morag C. Simpson. 1962. "Co-operatives and Agricultural Development in the Sudan," Journal of Modern African Studies, Vol. 6, No. 4, pp. 509-518.

Kiggundu, M. et al. 1983. "Administrative Theory and Practice in Developing Countries: A Synthesis," Administrative Science Quarterly, vol. 28, pp. 66-84.

Kikaho, E. E. 1976. Irrigation Development and Management Problems at Mbarali in the Usangu Plains, Southern High-lands of Tanzania. Paper C8, ODI Workshop on Choices in Irrigation Management, 27 Sept - 1 Oct 1976.

Kikaho, E. E. 1978. "Small Project Dependency on Surface Water Supply." Paper presented for the Workshop: Irrigation Management. Hyderabad, Inda.

Kilian, Tessler. 1973. "Méthode d'investigations pour l'analyse et le classement des bas-fonds dans quelques régions de l'Afrique de l'Ouest; classement d'aptitude des terres à la riziculture," Agronomie Tropicale, No. 9, pp. 846-924.

King, J. M. 1983. Livestock and Water Needs in Pastoral Africa in Relation to Climate and Forage. ILCA Research Report No. 7. Addis Ababa, Ethiopia: International Livestock Centre for Africa.

King, Jack Winfield, Jr., 1980. Analysis of Production Potential and Maintenance of Production for Selected Irrigable Soils by the Chari River in the Sahel Region of Chad. Ph.D. Thesis, Cornell University, 182 pp.

Kirsch, O.C. 1978. "Credit Unions Support for Rural Development Projects in Africa" Journal of Rural Coop-eration, Vol,1. 6 (2), pp. 143-156.

Kiwiet, Pieter. 1981. Elements de Bibliographie sur le secteur informel dans les pays du Sahel. Sahel D (8) 133. Paris: Club du Sahel, OCDE, 18 pp.

Kjekshus, H. 1977. Ecology, Control and Economic Development in East African History: the Case of Tanganyika 1885-1950. London: Heinemann Educational Books Ltd.

Klein, J. C. 1977. Determination des causes des anomalies de la crue Niger. Rapport intermediaire de la seconde phase d'étude/1977-79, 77 pp. Paris: Ministère de la Coopération/ORSTOM-Service Hydrologique.

Kloos, H. 1977. Schistosomiasis and Irrigation in the Awash Valley of Ethiopia. Ph.D. Thesis, University of California, Davis, 307 pp.

Kloos, H., A. Lemma, and G. Desole. 1978. "Schistosoma Mansoni Distribution in Ethiopia: a Study in Medical Geography," Annals of Tropical Medicine and Parasitology 72, 5, pp. 461-470.

Koegel, R.G. 1977. Self-Help Wells. FAO Irrigation and Drainage Paper 30. Rome: FAO, 78 pp.

Koehlin, Jean. 1977. Rapport de mission d'étude sur le milieu naturel et l'utilisation du sol dans la région de Maradi. Bordeaux/Paris: Université de Bordeaux II/DGRST (Projet de Recherche sur la Région de Maradi).

Kohel, R. J. and Lewis, C. F., eds. 1984. Cotton. (Agronomy Series Number 24.) Madison, Wisconsin: American Society of Agronomy, Inc; Crop Science Society of America, Inc.; and Soil Science Society of America, Inc.

Kohler, Jean Marie. 1974. Les Mosi de Kolongotomo et la collectivisation à l'Office du Niger (Notes Sociologiques), No. 37. Paris: ORSTOM - Travaux et Document No. 37, 64 pp.

Konings, P. 1981. "Peasantry and State in Ghana: The Example of the Vea Irrigation Project in the Upper Region of Ghana," Working Paper No. 5. Leiden, The Netherlands: African Studies Centre.

Korten, Frances. 1982. Building National Capacity to Develop Water Users' Associations: Experience from the Philippines. World Bank Staff Working Paper No. 528. Washington, D.C.: The World Bank, 65 pp.

Kortenhorst, L. F. 1980. "Factors Affecting the Viability of Smallholders Irrigation," Land Reclamation and Water Management Publication, No. 27, ILRI, Wageningen. (Also ILRI Report No. 20).

Kortenhorst, L. F. 1983. Workshop on Small-Scale Irrigation in Kenya--Summary Report. Wageningen: International Institute for Land Reclamation and Improvement.

Kostinko, Gain and Josue Dione. 1980. Rural Development in Senegal: An Annotated Bibliography Since 1975. African Rural Economy Paper No. 22. East Lansing, Mich.: Department of Agricultural Economics, Michigan State University.

Kowal, J. M. and D. T. Knabe. 1972. An Agroclimatological Atlas of the Northern States of Nigeria with Explanatory Notes. Zaria: Ahmadu Bello University Press.

Kowal, J.M and A.H. Kassam. 1978. Agricultural Ecology of Savanna: A Study of West Africa. Oxford: Oxford Univ. Press.

Kraatz. 1977. Revêtement des canaux d'irrigation. Rome: FAO, 223 pp.

Kraatz, D. and Stoutjesdijk, J. 1984. "Improved Headworks for Reduced Sediment Intake," pp. 167-179. In, Blackie, M. J. (ed.) African Regional Symposium on Small Holder Irrigation. Harare, Zimbabwe: Univeristy of Zimbabwe.

Kramer, E. W. and B. Stegemann. 1966. The Koki Lakes Reconnaisance Survey. Rome: FAO.

Kramer, E. W. 1968. Reconnaisance Survey Report of Potential Water Development in the Nyamugasani Catchment. Uganda: Food and Agriculture Organisation.

Kruck, Wolfgang. 1981. "Hydrogeologic Interpretations of Landsat Imagery in Arid Zones of South and West Africa," pp. 408-415. In, Deutsch, Morris et al. (eds.) Satellite Hydrology. Minneapolis: American Water Resources Association.

Kucera, K.P. 1984. "Accuracy of Landsat Imagery and Air Photography Interpretation in Predicting Soils and Land Suitability for Irrigation: An Analysis of Practical Surveys for Development of Three Contrasting Environments." Soil Survey and Land Evaluation, 4(1):8-17.

Kuebel, Peter. 1982. The Village Health Workers Train in the Sahel. A Manual for Planning, Implementation and Evaluation. Paris: Club du Sahel, 143 pp.

Kuester, P. and Wiggin, S. 1982. Proposals for the Development of the Ewaso Nyiro Irrigation Scheme Cluster, Isiolo. Nairobi: Ministry of Economic Planning and Development, Republic of Kenya.

Kussow, W., S.A. El-Swaify and J. Mannering (eds.). 1982. Soil Erosion and Conservation in the Tropics. American Society of Agronomy, Special Publication No. 43.

Kutilik, M. 1983. Soil Physical Properties of Saline and Alkali Vertisols. Soil Science Laboratory, Department of Irrigation and Drainage, Technical University, Prague, Czechloslovakia.

Laheuc, J. P. 1970. "Une Communauté Evolutive Mossi: Zaongho," Etudes Rurales, Vols. 37-38-39, pp. 150-172.

Lahuec, J. P. 1970. "Les jardins de saison sèche à Zaongtro (région de Koupela)," Cahiers de l'ORSTOM, Serie Sciences Humaines, Vol. 5, No. 2, pp. 67-87.

Lahilou, O. 1977. "L'irrigation localisée ou micro-irrigation," Hommes, Terres et Eaux, Vol. 6, No. 23, pp. 47-53.

Lal, R. 1981. "Analyses of Different Processes Governing Soil Erosion by Water in the Tropics." IAGS-AISH Publication No. 133:351-364.

Lal, R. and E. W. Russell, (eds.). 1981. Tropical Agricultural Hydrology: Watershed Management and Landuse. Chichester, England: John Wiley, 482 pp.

Lal, R. and J. S. Moomaw. 1978. "Techniques for Screening Rice Varieties for Drought Tolerance," pp. 285-292. In: Buddenhagen, I. W. and G. J. and Persley, eds, Rice in Africa. New York: Academic Press.

Lamagat, Jean Pierre. 1977. Détermination des causes des anomalies des crues du Niger (Mali). Etudes Statistiques Hauteurs et débits décadaires. Paris: Ministère de la Coopération/ORSTOM, 37 pp.

Lamouroux, M. 1969. Notice explicative No. 34 à la carte pédologique du Togo. (with map at 1:500,000) Paris: ORSTOM.

Lancelot, Yves. 1983. "L'example de Ruwana au Niger," Actuel Développement, No. 56-57, p. 59.

Landell Mills Associates. 1979. Mpongwe Pilot Project. Comparative Study of Settlement Schemes. Final report. Landell Mills Associates, P.O. Box 3000, Lusaka.

Langelier, P. 1980. "Détermination du régime hydraulique d'une culture de canne à sucre de milieu, en période de maturation, dans le nord de la Côte d'Ivoire," Agronomie Tropicale, 35, 3 pp. 232-239.

Langley, P. 1977. "A Self-Reliant Environment? The Possibility of a Technological Alternative." African Environment: Technological Relay Series. Dakar: IDEP.

Langley, Philip. 1983. "Bigger is not always better," World Water.

Larson, Thomas J. 1980. The Humbukushu of Ngamiland, Ecology and Settlement Pattern of a Riverine People. Ph.D. Thesis, University of Virginia, 320 pp.

Lassailly-Jacob, V. 1983. "Initiatives Paysannes et Interventions Etatiques dans la Mise en Valeur des Rives du Lac Volta au Ghana." Paper presented for International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Lassoudiêdre, A. 1978. "Quelques aspects de la croissance et du développement du bananier Poyo en Côte d'Ivoire. 5e partie. Conclusions générales et applications aux techniques culturales," Fruits, 33, 7/8, pp. 492-503.

Lateef, Noel V. 1980. Crisis in the Sahel: A Case Study in Development Cooperation. Boulder, Colo.: Westview Press, 287 pp.

Laucoin, Guy. 1971. "L'animation des aménagements hydro-agricoles; vers l'autogestion des aménagements au Niger," Développement et Civilisation, No. 44, Juin 1971, pp. 54-62.

Laucoin, Guy. 1973. "La gestion des aménagements hydro-agricoles au Niger," Développement et civilisations, No. 51, Janvier-Mars, 8 pp. 21-31.

Laurence, J. F. 1968. Consideration of the Non-Technical Factors Affecting the Success of Irrigation Schemes in Underdeveloped Areas with Particular Reference to Farm Size. MS Thesis, Department of Civil Engineering, University of Southampton.

Laya, Dioulde. 1969. Recherche et développement. Le projet de mise-en-valeur des cuvettes de Kutukale et Karma en pays Songhay. Niamey: IFAN/CNRS.

Lea, J. D. and G. Murdoch. 1964. Irrigation Farming, Bulletin 11. Swaziland: Department of Agriculture.

Leakey, C. L. A. and Willis, J. B. (eds.) 1977. Food Crops of the Lowland Tropics. London: Oxford University Press, 345 pp.

Le Buanec, B. 1975. "La Riziculture Pluviale en Terrain Draine; Situation, Problèmes, et Perspectives," Agronomie Tropicale, Vol. 30, No. 4, pp. 353-381.

Lecollais, Andre, Diallo, Yveline, Santoir, and Christian. 1980. Peuplement et cultures de saison sèche dans la vallée du Sénégal. Paris: ORSTROM.

Lecomte, B. 1978. "Participation paysanne à l'aménagement et techniques de projets," Revue Tiers Monde, Vol. 19, No. 73, Janvier-Mars.

Ledger, D. 1961. "Recent Hydrological change in the Rima Basin, Northern Nigeria," Geographical Journal vol. 127, pp. 477-487.

Ledger, D. 1969. "The Dry Season Flow Characteristics of West African Rivers." In, Thomas, M. F. and G. W. Whittington (eds.), Environment and Land Use in African Rivers London: Methuen, pp. 477-487.

Lee, C. W. and J. M. Maurice. eds. 1983. The African Trypanosomiases. (World Bank Technical Paper No. 4.) Washington, D. C.: The World Bank.

Lee, Joshua A. 1984. "Cotton as a World Crop." In: Kohel, R. J. and C. F. Lewis, eds., Cotton. Madison, Wisconsin: American Society of Agronomy.

Legoupil, J. C. 1972. "The Water Requirements of Crops in the Haut-Chelif," Agronomie Tropicale, 27, 2, pp. 212-220.

Le Houerou, H.N. 1980. "The Rangelands of the Sahel". Journal of Range Management. 33(1):41-46.

Leirat, R. "La SEMRY: Société d'expansion et de modernisation de la riziculture de Yagoua," Le Cameroun Agricole Pastoral et Forestier, No. 148, Juin, pp. 20-55.

Lemoine, C. and J. C. Prat. 1975. Etude de procédés de lutte contre l'évaporation sur les plans d'eau: Bilan d'une campagne. Ouagadougou: CIEH.

Lemoine, Jacques. 1963. La mise en valeur des eaux souterraines en Haute Volta et organisation de la recherche. ONU, Avril, 1963, 83 pp.

Lemoine, Jacques. 1981. Cours d'hydraulique villageoise. Orientation générale des projets d'hydraulique villageoise. Sophia Antipolis: CFFIGRE, 13 pp.

Leonard, David C. 1983. Traditional Field Crops. Washington, D.C.: Information Collection and exchange, Peace Corps, 176 p. (Appropriate Technology for Development Manual No. M-13).

Lericollais, A. 1978. La Vallée du Sénégal. Paris: Ecoles des Hautes Etudes en Sciences Sociales--CNRS--ORSTOM.

Lericollais, A. 1979. "Activités Traditionelles et Insertion dans les Casiers Irriguées de la Vallée du Sénégal," Maîtrise de l'Espace Agraire et Développement en Afrique Tropicale. Paris: Editions de l'Office de la Recherche Scientifique et Technique Outre-Mer, pp. 265-279.

Lerman, A. (ed.). 1978. Lakes: Chemistry, Geology, Physics. New York: Springer Verlag.

Le Roy, E. "Reforme Foncière et Développement: L'Exemple du Sénégal," African Perspectives, pp. 67-81.

Lesotho Ministry of Agriculture. 1977. Soil Survey of Thaba Bosiu Project (basic report). Lesotho Office of Soil Survey Conservation Division.

Levasseur, J. C. 1981. Les politiques de développement de l'agriculture en Afrique de l'Ouest. Première session de l'action de formation, Dakar, 12 janvier-13 février 1981. République du Senegal: FAO, 22 pp.

Levasseur, J. C. 1981. Les systèmes de production rizicole dans les pays de l'Afrique de l'Ouest. Dakar 12, janvier - 12 février 1981. République du Sénégal: FAO, 22 pp.

Levine, Gilbert. 1970 "Hardware and Software: An Engineering Perspective on the Mix for Irrigation Management," Paper presented at the Workshop on Irrigation Research. Los Sanos, Philippines: International Rice Research Institute.

Levine, Gilbert. 1977. "Management Components in Irrigation System Design and Operation," Agricultural Administration, vol. 4, pp. 37-48.

Lewis, I. M. 1975. Abaar - The Somali Drought. London: International African Institute.

Lewis, John Van Dusen, Sidney F. Bowers, Elon Gilbert, Robert I. Jackson, and William Scott. 1983. West African Rice Research and Development. AID Project Impact Evaluation Report No. 44: U.S. Agency for International Development.

Leynaud, E. and M. Roblot. 1961. La modernisation dans la Haute Vallée du Niger. Paris: BDPA, 4 Volumes.

Leynaud, Emile. 1964. Les cadres sociaux de la vie rurale dans la Haute Vallée du Niger. Paris: BDPA, 2 Volumes, 253 pp.

Leynaud, Emile. 1964. Contribution à l'étude des structures sociales et de la modernisation rurale dans la Haute Vallée du Niger. Paris: BDPA, 3 Volumes.

Linacres, O. F. 1981. "From Tidal Swamp to Inland Valley: on the Social Organisation of Wet Rice Cultivation Among the Diola of Senegal," Africa, Vol. 51, No. 2, pp. 557-595.

Lines, G. E. and R. J. Pattison. 1975. "Progress Report on Technology and Economics of Irrigated Pasture in the Awash Valley." UNDP/FAO/ETH 72/ODG FAO Informal Technical Report 25.

Little, K. L. 1951. The Mende of Sierra Leone. Routledge and Kegan Paul. Ch. IV: Rice Farming and Land Tenure.

Litzengberger, S.C. (ed.) 1974. Guide for Field Crops in the Tropics and Subtropics. Washington, D.C.: Agency for International Development.

Lium, Tore and Skofteland, Egil (eds.) 1983. Proceedings, Water Master Planning in Developing Countries. Oslo: Norwegian National Committee for Hydrology.

Lombard, Pierre. 1976. "Les petits pêrimètres irrigués du Niger," Cahiers du CENECA, Colloque Internationale, rapport No. 4222.

Longenecker, D. E. and L. J. Erie, 1968. "Irrigation Water Management." In: Elliot, Fred C., Marvin Hoover, and Walter K. Porter, Advances in Production and Utilization of Quality Cotton. Ames, Iowa: Iowa State University Press.

Lowdermilk, Max K. 1978. "Farm Water Management in Irrigation Systems: The Crucial Role of Farmer Organizations," pp. 1-59 (Chap. 7). In:

Lundqvist, J., Lohm, U. and Falkenmark, M. (eds.) 1985. Strategies for River Basin Management. Environmental Integration of Land and Water in a River Basin. Dordrecht, the Netherlands: D. Reidel Publishing Co.

Maasland, M. Mark, G. R. L., and A. E. A. Schumacher. 1976. Les besoins d'aide pour l'aménagement du Bassin du fleuve Niger. Ottowa: ACDC/Direction de l'Afrique francophone, 33 pp.

MacLeod, N. H., Schubert, J. S. and Anaeijonu, P. 1977. "Report on the Sky-lab 4 African Drought and Arid Lands Experiment," pp. 263-286. In, Skylab Explores the Earth. Washington D.C.: NASA (SP-380).

Madagascar, République de. 1964. Aménagement hydroagricole du Marais d'Ambila. Tananarive: Ministère de l'agriculture et du paysannat.

Madagascar, République de. 1964. Aménagement hydroagricole de la plaine d'Anjiajia: Dossier technique. Ministère de l'agriculture et du paysannat, direction de génie rural et de l'hydraulique agricole.

Madagascar, République de. 1964. Aménagement hydroagricole du périmètre de la Basse-Ikopa. Tananarive: Ministère de l'agriculture et du paysannat.

Mageed, Y. A. 1985. "The Integrated River Basin Development; The Challenge to the Nile Basin Countries," pp. 151-160. In, Lundqvist, Jan, et al. (eds.) Strategies for River Basin Management. Dordrecht, the Netherlands: D. Reidel.

Magnant, J. P. 1984. "Les réactions paysannes à un projet de développement rizicole au sud de N'djamena" Développement agricole et participation paysanne. Un exemple: la politique de l'eau en Afrique. Paris: CNRS-CEJC.

Maiga, Mahamadou. 1976. Capitalisme, exploitation des resources hydrauliques du fleuve sénégal et dé veloppement des pays riverains (Guinée, Mali, Mauritanie, Sénégal). Ph.D. Thesis, Univ. of Paris.

Maiga, Mahamadou. 1976. "The Policy of Rice Import Substitution: The Case of the Senegal River Valley and Delta". African Development, Vol. 7, No. 2, pp. 44-57.

Maighien, R. No date. Carte Provisoire de Guinée au 1:5,000,000. Revised by A. Kawalec. (Unpublished).

Maighien, R. 1965. Carte pédologique du Sénégal au 1:1,000,000, notice. Dakar-Hann: ORSTOM.

Mailland, Larrieux, David, and Garaut. 1966. Programme générale d'aménagement dans la haute vallée du Niger, 2 Volumes. Paris: BBPA, 168 pp.

Maille, Rafford, Mayer. 1976. Projet de formation de personnel de la SAED et des groupement de producteurs. Paris: SATEC, Ministère du développement rural et de l'hydraulique/SAED, Dakar, 63 pp.

Mainet, Guy and Guy Nicolas. 1964. La vallée de Goulbi de Maradi: Enquête socio-économique. Niamey: IFAN/CNRS, Etudes Nigeriennes, No. 16.

Mainguet, Monique. 1979. La désertification. Reins: Travaux de l'institut Géographique de Reims, various articles on drought.

Makadho, J. M., 1984. "A Review of Some Factors Affecting the Viability of Small Holder Irrigation Schemes in Africa," Blackie, M. J. (ed.). African Regional Symposium on Small Holder Irrigation Harare, Zimbabwe: University of Zimbabwe.

Makin, M. et al. 1976. Prospects for Irrigation Development around Lake Zwai, Ethiopia. Land Resource Study No 24A, Land Resources Division, Ministry of Overseas Development, England.

Malacamp, Jean. 1979. "Utilisation de la télédetection spatiale dans les projets d'etudes et de surveillance des barrages," Bulletin de Liaison CIEH, No. 39-40 Dec. 79 - March 80, pp. 2-11.

Mali, République du. 1972. Projet de développement des cultures vivrières dans la zone lacustre. Bamako: Ministère du Developpement Rurale, 3 Volumes.

Mali, République du. Fonds d'Aide et de Coopération. 1984. Synthèse et bilan des prestations-fourniés par SOGREAH à l'Office du Niger de 1978 a 1986. Grenoble: SOGREAH.

Mali, République du, Ministère de la Production. 1973. Etude socio-économique de la zone du Lac Horo et des mares de Niafunké et de Diré. Paris: SEAE/SEDES, 3 Volumes.

Mali, République du. 1983. Mali Land and Water Resources. Vol. 1, Atlas. Vol. 2, Technical Report. Vol 3, Annexes. New York: TAMS for the Ministry of Rural Development, Republic of Mali.

Maltby, Edward. 1986. Waterlogged Wealth: Why Waste the World's Wet Places? London: Earthscan, 200 pp.

Mamadou, O. 1978. Contribution à l'étude socio-économique sur les aménagements hydro-agricole de Saga-Libore et N'dounga. Niamey: Institut de Recherches en Sciences Humaines.

Manger, L. D. 1981. The Sand Swallows Our Land. Over-Exploitation of Productive Resources and the Problem of Household Viability in the Kheiran - A Sudanese Oasis. Department of Social Anthropology, University of Bergen, Norway, Occasional Paper 24.

Mann, K. S. 1973. Pilot Irrigation Development Scheme, Asutsuare, Ghana. Farm Management and Settlement; Based on the Work of K. S. Mann. Rome, Italy: Food and Agriculture Organisation.

Manning, H. L. 1956. "The Statistical Assessment of Rainfall Probability and its Application in Uganda Agriculture," Proceedings of the Royal Society B144, pp. 460-80.

Mansell Prothero, R. 1972. People and Land in Africa South of the Sahara. London: Oxford University Press.

Manteuffel, H.M. and W.E. Tyner. 1980. "Benefit-Cost Analysis of Small Irrigated Perimeters--A Sahelian Case Study." Purdue University. Workshop on Sahelian Agriculture, May 1980. Lafayette, Ind.: Dept. of Agricultural Economics, Purdue University.

Marchal, J. Y. 1970. "Un Exemple de colonisation agricole à Madagascar: Antenety-Ambohidua (Sous Préfecture de Betafo)," Etude Rurales, Nos. 37-38-39, pp. 397-409.

Marchal, J. Y. 1974. "L'Office du Niger: étude de prospérité paysanne," Revue Canadienne des Etudes Africaines. VIII, No. 1, pp. 73-98.

Marchal, J. Y. 1976. "Un périmètre agricole en Haute Volta: Guiedougou, vallée de Sourou," Cahiers ORSTOM. Série Sciences Humaines, No. 1.

Margat, J. and K. F. Saad. 1984. "Deep-lying Aquifers: Water Mines under the Desert?" Nature and Resources XX (2) pp. 7-13.

Markham, R.H. and A.J. Babbedge. 1979. "Soil and Vegetation Catenas on the Forest-Savanna Boundary," Ghana- Biotropica, 11(3):224-234.

Martin, D. No date. Carte provisoire au 1:5,000,000. Libreville: ORSTOM.

Martin, D. and P. Segalan. 1966. Notice Explicative de la Carte Pédologique du Cameroun Oriental au 1:1,000,000. Yaoundé: ORSTOM.

Martin, P. 1976. "Amélioration des Conditions de Production du Riz Flottant du Mali (Période 1963-73)," Agronomie Tropicale, Vol. 31, No. 2, pp. 134-201.

Masao, F.T. 1975. "The Irrigation System in Uchagga: An Ethno-Historical Approach." Tanzania Notes and Records. 75 pp. 1-8.

Mascarenhas, Adolfo. 1985. "Rationale for Establihsing a River Basin Authority in Tanzania," pp. 317-328. In, Lundqvist, Jan, et al. (eds.) Strategies for River Basin Management. Dordrecht, the Netherlands: D. Reidel.

Mascarenhas, Adolfo, James Ngana and Masao Yoshida. 1985. Opportunities for Irrigation Development in Tanzania. JRP Series. No. 52. Tokyo: Institute of Developing Economies, 114 pp.

Masefield, G.B. 1952. "Farming Systems and Land Tenure," Journal of African Administration, Special Supplement, October.

Massane, G. S. 1979. Irrigation et développement dans la vallée du Niger: le cas des aménagements hydro-agricoles en amont de Niamey. Niamey: Université de Niamey, pp. 175.

MAT. 1978. "Quelques exemples de nouvelles techniques d'irrigation en Afrique," Machinisme Agricole Tropical, No. 64, Oct.-Dec. 1978, pp. 3-17.

MAT. 1979. "Irrigation de la canne à sucre," Machinisme Agricole Tropical. No. 67 Juillet - Sept. 1979, pp. 49-58.

Mather, T. H. 1984. Environmental Management for Vector Control in Rice Fields. FAO Irrigation and Drainage Paper, no. 41. Rome: FAO, 152 pp.

Mathieu, P. 1983. "Agriculture irriguée, réforme foncière, participation paysanne; Le cas de la zone du Lac de Guiers dans la vallée du fleuve Sénégal." Paper presented to International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de l'Eau en Afrique. Paris: CNRS-CEJC.

Mathieu, P. 1984. "Agriculture irrigué, réforme foncière, participation paysanne, le cas de la zone du lac Guiers dans la vallée du fleuve Sénégal," Développement agricole et participation paysanne. Un exemple la poli-tique de l'eau en Afrique. Paris: CNRS-CEJC.

Mathieu, P. 1985. "Agriculture irriguée, réforme foncière, participation paysanne: le cas de la zone du lac Guiers dans la vallée du fleuve Sénégal," pp. 589-607. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Développement agricole et participation paysanne. Paris: Economica.

Maton, Guy. 1965. Rapport d'une mission d'étude relative au projet d'aménagement hydro-agricole de la rive gauche du delta Sénégal. Paris: SEAE/DATC, 35 pp.

Maton, Guy. 1969. "La mise en valeur des polders du lac Tchad," Coopération et Développement, Vol. 27, pp. 25-34.

Maton, Guy. 1970. Rapport de Mission en Mauritanie. Paris: Secretariat d'Etat aux Affaires Etrangeres, 40 pp.

Maton, Guy. 1972. Mise en valeur des polders du Lac Rapport de mission effectuée du (8)au 29 janvier, 1972. Paris: SEAE/DAD/Département de développement rural, 21 pp.

Maton, Guy. 1974. Termes de réference de l'étude de factibilité du projet et de mise en valeur de la plaine de Niena-Dionkele, Haute Volta. Paris: Ministère de la Cooperation, 15 pp.

Maton, Guy. 1974. "La politique des grands barrages hydro-agricoles," Actuel Développement, No. 3, Sept, Oct. 1974, pp. 32-37.

Mattern, David. 1981. "Final Report, Action Blé-Diré," (unpublished report). Bamako: USAID/Mali.

Matthews, I. G. S. 1955. The Canals of the Gezira Canalisation Scheme and the Design of the Goneid Pump Scheme in the Sudan. London: Proc. Inst. Civil Engineers.

Maucor, J. B. 1979. Les micro centrales hydrauliques. Paris: GRET, Ministère de la Coopération, 125 pp.

Mauritanie, République Islamique de. 1960. Aménagement localisés dans la vallée du Sénégal. Nouakchott: Service Génie Rural.

Mauritanie, République Islamique de, Ministère du Plan/Bureau Hydrogéologique. 1966. Synthèse hydrogéologique et aménagement hydraulique du Sud-Est Mauritanien, 2 Volumes. Neuilly/Seine: BURGEAP.

Mauritanie, République Islamique de, SONADER. 1980. Etude de faisabilité d'un programme d'aménagement de péri-mètres villageois sur la rive droite du fleuve Sénégal. Paris: SATEC, 1980, 10 pp.

Mauritanie, République Islamique de. 1981. Irrigated Agri-culture (RAMS Project--rural assessment and manpower surveys). Nouakchott: Ministry of Economy and Finance, 182 pp.

Maurya, P. R. and Sachan, R. S. 1984. "Large- and Small-Scale Irrigation Systems in Nigeria: A Comparative Study," pp. 273-286. In, Blackie, M. J. (ed.) African Regional Symposium on Small Holder Irrigation. Harare: Univ. of Zimbabwe.

Mayer, J. 1971. Ricicultures traditionelle et ameliorée, 3 Volumes. Paris: SATEC.

Mayer, J. 1973. Note sur la sécheresse en Afrique Sahelienne. La sécheresse de 1972 a accusé le problème vivrier du Sénégal. L'irrigation par pompage permet-trait d'assurer une agriculture intensive et rentable. Paris: SATEC, 27 pp.

Mayer, J. 1973. "Le microhydraulique à Madagascar. Le test de l'opération de productivité rizicole," Techniques et Développement, No. 9, Sept.-Oct. 1973, pp. 44-48.

Mayer, J. 1979. "Un grand programme de périmètres d'irrigation villageois en Afrique Sahelienne," Maitrise de l'espace Agraire Développement en Afrique Tropicale. Paris: Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), Mémoires, No. 89, pp. 317-321.

Mbawala, P. P. 1979. Irrigation Development in Mainland Tanzania: the Issue of Farmer Local Organisation - A Suggestion. Dept. of Sociology and Rural Sociology, University of Missouri, Columbia, Missouri 65201, USA. Agricultural Administration, Vol. 6, No. 2, 1979, pp. 99-110.

Mbawala, P. P. 1980. "Irrigation Development and Peasant Participation in Tanzania," Eastern Africa Journal of Rural Development, 13, 1/2, pp. 68-91.

Mbawala, P.P. 1981. Irrigation Management Alternatives for Tanzania. Ph.D. Thesis, University of Missouri, 207 pp.

Mburu, J. S. 1982. Agriculture in Kiambu Nature Reserves. London: Land Resources Division Overseas Development Administration.

McConnen, Richard J. 1986. "Economic Aspects of Small-Scale Irrigation Development," pp. 19-52. In, Coward, E.W., Jr. et al., Watering the Shamba. Ithaca, New York: Cornell University.

McCuen, R. H. et al. 1977. Flood Flow Frequency for Ungauged Watersheds: A Literature Evaluation. Washington, D.C.: Agricultural Research Service. United States Department of Agriculture.

McIntire, John. 1981. Food Security in the Sahel: Variable Import Levy, Grain Reserves, and Foreign Exchange Assistance. IFPRI Research Report No. 26. Washington, D. C.: International Food Policy Research Institute, 70 pp.

McIntire, John. 1981. In. Rice in West Africa: Policy and Economics by Scott R. Pearson, J. Dirck Stryker and Charles P. Humphries, Stanford, California: Stanford University Press.

McJunkin, Eugene. 1979. Hand Pumps for use in Drinking Water Supplies in Developing Countries. The Netherlands: 1977 International Reference Centre for Community Water Supply, Technical Paper No. 10.

McJunkin, F.E. 1970. Engineering Measures for Control of Schistosomiasis. Chapel Hill, N.C.: Dept. of Environmental Sciences and Engineering, School of Public Health, Univ. of North Carolina (for USAID), 66 pp.

McJunkin, F.E. 1975. Water, Engineers, Development and Disease in the Tropics. Washington, D.C.: Agency for International Development; basic source, with emphasis upon schistosomiasis.

McNetting, Robert et al. 1980. "Interior Niger Delta of Mali," pp. 373-454. - Reyna, Stephen (ed.) Sahelian Social Development. Abidjan: Regional Economic Development Services Office (REDSO), West Africa, USAID, 702 pp.

Medani, A.I. 1971. "Consumption Patterns of the Gezira-Managil Tenants," Sudan Notes and Records, vol. 52, pp. 79-87.

Meek, C. K. 1952. "Some Social Aspects of Land Tenure in Africa," Journal of African Administration, Special Supplement, October.

Meillasoux, Claude. (1974). "Development or Exploitation: Is the Sahel Famine Good Business?" Review of African Political Economy, Vol. 1, pp. 27-33.

Mensching, Horst G. with V. Haarmann (eds.) 1982. Problems of the Management of Irrigated Land in Areas of Traditional and Modern Civilization. IGU Working Group on Resource Managment in Drylands. Hamburg: IGU, 174 pp.

Meredith, William R., Jr., and Robert R. Bridge. 1984. "Genetic Contributions to Yield Changes in Upland Cotton," pp. 75-87. In: Fehr, W. R., ed., Genetic Contributions to Yield Gains of Five Major Crop Plants. Madison, Wisconsin: Crop Science Society of America, American Society of Agronomy.

Merian, Pierre. 1975. Toute la nuit on danse autour d'un puits du Sahel. Les micro-réalisations au service du développement. Paris: 127 pp.

Merlier, H. 1982. "La Lutte Contre les Mauvaises Herbes en Riziculture Pluviale en Côte d'Ivoire," Agronomie Tropicale, Vol. 37, No. 4, pp. 408-410.

Merlin, Marc. Cabinet d'études. 1982. SAED (St. Louis) Périmètre de Dagana et N'Dieba: Electrification des stations de pompage. Lyon.

Merryman, J. L. and M. H. Merryman. 1980. The Potential for Agricultural Development in a Pastoral Society: A Sociological Study of the Peoples of Garissa District. Report, Ministry of Cooperative Development, Kenya, No. 6.

Meteorological Office. 1983. "Tables of Temperatures, Relative Humidity, Precipitation and Sunshine for the World," Part 4, Africa, the Atlantic Ocean South of 35 Degrees N and the Indian Ocean. Bracknell, U. K.: Meteorological Office.

Metzenthin, Thierry. 1974. Compte d'exploitation prévisionel de l'aménagement hydro-agricole de Sona-Lossa (Niger). Organisation et gestion des aménagements du fleuve - Rapport de stage. Nogent Marne: NEAT.

Miller, Duncan (ed.). 1980. Etudes sur le développement rural, Vol. II, Etudes sur les systèmes d'approvi-sionnment en eau en milieu rural. Paris: OCDE.

Miller, M. J. 1982. "Parasites of Man and Arthropod Disease Vectors in Communities of a Water Development Program on the Senegal River Basin," pp. 279-334. In, Meerovitch, E. (ed.) Aspects of Parasitology. Montreal, Canada: Institute of Parasitology, McGill University.

Miller, Richard P. 1985. Peasant Autonomy and Irrigation: Innovation in the Senegal River Basin. Ph.D. thesis, Northwestern University, Evanston, Illinois.

Milne, G. 1947. "A Soil Reconnaisance Journey Through Parts of Tanganyika Territory," Journal of Ecology, vol. 35, pp. 192-265.

Minderhoud, P. 1981. "Planning of Flood Control and Land Use in Relation to Water Management in the Lower Kafue Catchment Area in Zambia." Eleventh Congress on Irriga tion and Drainage, Part 3. New Delhi, India: International Commission on Irrigation and Drainage.

Ministère de la Coopération. 1965. Etude monographique de 31 pays Africains, 4 Volumes. Paris: COGERAF.

Ministère de la Coopération/SAED. 1967. Aménagement du delta du Sénégal. Projet hydro-agricole Drain vers le n'Diel, Aout, 1967. Paris: SCET/Ministère de la Cooperation.

Ministère de la Coopération/SAED. 1968. Aménagement du delta du Sénégal Avant projet hydro-agricole--Cuvettes de Djeuleuses et de Dcambar--Cuvette de Kassak-sud. Paris: SCET--Ministère de la Coopération.

Ministère de la Coopération. 1971. Aspects socio- économiques des aménagements hydro-agricoles. Paris: SEDAGRI.

Ministère de la Coopération. 1975. Manual de l'adjoint t chnique du génie rurale; travaux sur un périmètre d'irrigat on. Paris: SOGREAH, 381 pp.

Ministère de la Coopèration. 1976. Rapport de la mission d'évaluation du projet de développement integré du perimètre de Baguineda. Paris: Ministere de la Cooperation, 52 pp.

Ministère de la Coopération. 1976. Role possible de la vallée du Sénégal dans les économies de la Mauritanie et du Sénégal. Analyse des projets de OMVS. Paris: Ministere de la Cooperation, 51 pp.

Ministère de la Coopération. 1977. Détermination des causes des anomalies des crues du Niger. Remise en état du réseau hydrométrique au Mali. Annuaire 1976. Paris: Ministère de la Coopération/ORSTOM.

Ministère de la Coopération. 1977. Manuel de gestion des périmètres irrigués. Paris: SCET, 272 pp.

Ministère de la Coopération. 1978. Note de présentation sur les polders de Bol au Tchad. Paris: Ministère de la Coopération, 220 pp.

Ministère de la Coopération. 1979. Etude des changes recurrentes des aménagements hydro-agricole au Niger, analyse des principaux résultats économiques. Paris: SEDES, 155 pp.

Ministère de la Coopération. 1979. Evaluation des quantités d'eau necessaire aux irrigations. Paris: Ministère de l'Agriculture, CIGREF, Groupement d'Aix en Provence, Division d'Irrigation.

Ministère de la Coopération. 1980. Programme de Réparation de Barrages en Terre en Haute-Volta. Grenoble: SONGREAH, Jan. 1980.

Ministère de la Coopération. 1981. Développement agricole de la zone de Mbanza-Ngunga, 4 Volumes. Paris: Ministère de la Coopération/FAC.

Ministère de la Coopération. 1982. Evaluation économique de l'aménagement de la rive gauche du fleuve Sénégal, 3 Volumes. Paris: Ministère de la Coopération/CCCE.

Ministère des trauvaux publics et des transports. 1964. Données sur l'hydrologie et la navigabilité du fleuve Niger. November. Paris: Ministère des travaux publics et des transports.

Ministry of Agriculture. 1978. "The Provision of Water for Agriculture," Land Administration Journal, Vol. 1, No. 1, pp. 41-42, BIDS, in English (Ja 8009).

Miskin, A. B. 1953. "Land Registration," Journal of African Administration, Vol. 5, No. 2, pp. 72-80.

Missao de Pedologia de Angola e Mozambique. 1968. Carta generalizada dos solos de Angola (1:3,000,000 aproximazao). Memorias da Junta de Investigacoes do Ultramar, No. 56, Lisboa.

Mitchell, A. J. B. 1976. The Irrigation Potential of Soils along the Main Rivers of Eastern Botswana - a Reconnaisance Assessment. Land Resource Study No 7, Land Resources Division, Ministry of Overseas Development, England.

Mitchell, D. S. 1977. "Water Weed Problems in Irrigation Systems," Arid Land Irrigation in Developing Countries Barton Worthington, E. (ed.). London: Pergamon Press, pp. 317-328.

Mock, Josef F. (ed.) 1985. Traditional Irrigation Schemes and Potential for their Improvement. DVWK Bulletin, no. 9. Hamburg: Verlag Paul Parey.

Mohamed, G.B. 1982. An Analysis of Smallholder Rainfed Crop Production Systems: A Case Study of the Nuba Mountains Area, Western Sudan. Ph.D. Thesis, Michigan State University, 280 pp.

Mohamed, K. 1979. "The Projects for the Increase of the Nile Yield with Special Reference to Jonglei Project," pp. 1799-1821. In, Water Development and Management: Proceedings of the United Nations Water Conference,, Mar del Plata, Argentina, march 1977. New York: Pergamon Press.

Mohamed, S. S. et al. 1979. "Electrical Resistivity Investigations in Clarifying the Subsurface Geological Sequences and Groundwater Conditions of Abu Mina Basin (Northwestern Coastal Zone, Egypt)," International Association of Scientific Hydrology, The Hydrology of Areas of Low Precipitation, pp. 349-354.

Mohrmann, J. C. J. 1958. "Irrigation par Aspersion. Aspects Agricoles, Techniques et Economiques." Bulletin Agricole du Congo Belge, Vol. 49, No. 4, pp. 877 à 921.

Mondot-Bermard, Jaqueline. 1982. Les études en nutrition et alimentation dans les pays du Sahel. Bibliographie analytique. Paris: Club du Sahel/ OCDE, 74 pp.

Moniad, F. 1977. Détermination des causes des anomalies des crues du Niger. Rapport de synthèse. 1975-77, Paris: ORSTOM, Service Hydrologique/BDPA--Ministère de la Coopération, 63 pp.

Monnier, Pierre. 1967. Etude socio-économique des vallées d'Ibohamane et de Tegef. Paris/Niamey: CNRS/IFAN, 122 pp.

Montgomery, John D. 1983. "When Local Participation Helps." Journal of Policy Analysis and Management, Vol 3, No. 1, pp. 90-105.

Moorman, F. R. and D. J. Greenland. 1980. "Major Production Systems Related to Soil Properties in Humid Tropical Africa." In: Soil-Related Constraints to Food Production in the Tropics. Manila, Philippines: IRRI.

Moorman, Frans R. and Nico van Breemen. 1978. Rice: Soil, Water, Land. Manila: International Rice Research Institute.

Moran, E. F. (ed.). 1979. Changing Agricultural Systems in Africa. Department of Anthropology, Indiana University, USA, Studies in Third World Societies, 8, 138 pp.

Moreau, M. 1967. Réalisation de barrage en investissement travail, Haute Volta: Rapport de Travaux. Paris: BDPA, 42 pp.

Moreno, E. F. 1974. "O Plano do Cunene - desafio ao futuro de Angola," Formento 12, 1, pp. 3-12.

Moris, J. R. 1981. Managing Induced Rural Development. Bloomington, Indiana: International Development Institute, 190 pp.

Moris, J.R. 1984. "Managing Irrigation in Isolated Environments: A Case Study of Action Blé-Diré, Mali," African Regional Symposium on Small Holder Irrigation Blackie, M. J., (ed.). Harare, Zimbabwe: University of Zimbabwe.

Moris, J. R. 1987. "Irrigation as a Privileged Solution in African Development,: Development Policy Review, vol. 5, no. 2, pp. 99-123.

Moris, J. R. 1987. "Incentives for Effective Agricultural Extension at the Farmers/Agency Interface," pp. 199-224. In, Rivera, William and Schram, Susan (eds.) Agricultural Extension Worldwide. London: Croom Helm.

Moris, J. R., D. J. Thom, R. Norman. 1984. "Prospects for Small-Scale Irrigation Development in the Sahel," Water Management Synthesis Report 26. Utah State University, Logan, Utah.

Moris, J.R., and D.J. Thom. 1985. African Irrigation Overview: Summary. Water Management Synthesis, Report 37. Logan, Utah: Utah State University.

Morris, D.M. 1974. What is a famine? Economic and Political Weekly, vol. 1, no. 4, pp. 1855-1864.

Morris, D.M. and S.K. Brandel. 1982. Appropriate Indicators of Social Progress in the Sahel. A report to the OECD Club du Sahel and the CILSS. Paris: Club du Sahel, 129 pp.

Morris, W.H.M. (ed). 1980. Second Workshop on Sahelian Agriculture. Lafayette: Purdue University.

Morss, Elliott R, John K. Hatch, Donald R. Mickelwait, and Charles F. Sweet. 1975a. Strategies for Small Farmer Development: An Empirical Study of Rural Development Projects, Volume I. Washington, D. C.: Development Alternatives, Inc.

Morss, Elliott R., John K. Hatch, Donald R. Mickelwait, and Charles F. Sweet. 1975b. Strategies for Small Farmer Development: An Empirical Study of Rural Development Projects, Volume II, Case Studies. Washington, D. C.: Development Alternatives, Inc.

Morth, H. 1967. "Investigation into the Meteorological Aspects of the Variations in the Levels of Lake Victoria," Memoirs, East African Meteorological Department, Vol. 4 (2) pp. 1-23.

Mosrin, J. 1963. Historique des polders du lac Tchad. Fort Lamy, 17.

Mosrin, J. 1966. Note concernant le développement de l'entreprise "polders." Fort Lamy: Direction Générale Economique et Transportation, 17 pp.

Moss, R.P. (ed.). 1968. The Soil Resources of Tropical Africa. Massachusetts: Cambridge University Press.

Moss, R. P. 1969. "An Ecological Approach to the Study of Soils and Land Use in the Forest Zone of Nigeria," pp. 385-407. In, Thomas, M. . and Whittington, G. W. (eds.) Environment and Land Use in Africa. London: Methuen.

Mounier, Frederic. 1986. "The Senegal River Scheme: Development for Whom?: pp. 109-119. In, Goldsmith, E. and Hildyard, N. (eds.) The Social and Enviornmental Effects of Large Dams, vol. 2, Case Studies. Camelford, Cornwall: Wadebridge Ecological Centre.

Moyal, Pascal. 1982. "Deux Foreurs du Riz Irrigué Nouveaux pour la Côte d'Ivoire, Hydrellia prosternalis Deeming (Diptera, Ephydridae) et Pachylophus beckeri Curran Dipetera, Chloropidae)," Agronomie Tropicale, Vol. 37, No. 3, pp. 295-305.

Moyamba Agricultural Development Company. 1981. Evaluation Report and Feasibility Analysis, Moyamba Agricultural Development Company, Sierra Leone.

Muchena, F.N. 1982. "An Outline of the Major Soils of Kenya." J.N. Qureshi (ed.). Soil Management Under Intensive Cultivation. Soil Science Society of East Africa, Nairobi, Kenya, pp. 4-18.

Muller, R.A. 1973. "L'anthraenose des baies du cafeier d'Arabie (Coffea arabica L.) due a une forme virulente du Colletotrichum Coffeanum Noack," Cafe Cacao Thé, vol. 17, no. 4,, pp. 281-312.

Muller, R. A. 1975. "L'irrigation précoce, assurance pour une production regulière de haut niveau du cafeier arabica," Cafe Cacao Thé, vol. 19, no. 2, pp. 95-122.

Munsch, H. 1982. Kooperationsformen zur Risikominderung in Sudan: - eine Untersuchung uber Schutzfunktionen "traditionaler" und "moderner" Genossenschaften im New Halfa-Bewasserungsgebiet. Arbeiten: Institut fur Afrika-Kunde, Muchen, German Federal Republic, Report No. 38.

Mupawose, R. 1984. "Irrigation in Zimbabwe," African Regional Symposium on Small Holder Irrigation (Blackie, M.J. (ed.)). Harare, Zimbabwe: University of Zimbabwe.

Murdoch, G. 1963. Soil Map of Swaziland at 1:1,000,000. Mbabane: Land Utilization Department.

Murdoch, G. 1968. Soils and Land Capability in Swaziland. Mbabane: Ministry of Agriculture.

Murphy, H.F. 1959. A Report on the Fertility Status of Some Soils of Ethiopia. Addis Ababa: Imperial Ethiopian College of Agriculture and Mechanical Arts, Experiment Station Bulletin No. 1.

Murphy, Josette. 1983. Strengthening the Agricultural Research Capacity of the Less Developed Countries: Lessons from the AID Experience. Washington, D. C.: U. S. Agency for International Development.

Murphy, Josette and Leendert H. Sprey. 1980. The Volta Valley Authority: Socio-Economic Evaluation of a Resettlement Project in Upper Volta. West Lafayette, Indiana: Purdue University.

Murray-Rust, D. Hammond. 1973. "Soil Erosion and Reservoir Sedimentation in a Grazing Area West of Arusha, Northern Tanzania," pp. 325-343. In, Rapp, Anders, Berry, L. and Temple, P. (eds.) Studies of Soil Erosion and Sedimentation in Tanzania. BRALUP Research Monograph No. 1. Dar es Salaam: Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam.

Nabos, J. 1976. "L'Amelioration de l'Oignon (Allium cepa L.) au Niger," Agronomie Tropicale, Vol. 31, No. 4, pp. 387-397.

Naigeon, Christopher. 1981. "L'aménagement hydraulique régional" Afrique Agriculture, Les techniques Françaises en Afrique, No. 72, pp. 21-39.

National Academy of Sciences. 1974. More Water for Arid Lands. Promising technologies and research opportunities. Washington, D.C.: National Academy of Sciences.

National Academy of Sciences. 1977. Resource Sensing from Space: Prospects for Developing Countries. Washington: National Academy of Sciences.

National Academy of Sciences 1979. Tropical Legumes: Resources for the Future. Washington, D. C.: National Academy of Sciences, 328 pp.

National Research Council. 1982. Ecological Aspects of Development in the Humid Tropics. Prepared by the Committee on Selected Biological Problems in the Humid Tropics. Washington, D. C.: National Academy Press.

National Research Council. 1983. Environmental Change in the West African Sahel. Washington, D.C.: Advisory Committee on the Sahel, Board on Science and Technology for International Development, Office of International Affairs. National Academy Press.

Navez, S. 1976. Evaluation de coût du mètre cube d'eau rendu culture suivant les moyens mis en oeuvre. Dakar: Ministere du développement rural et de l'hydraulique, 27 pp.

Nelson, Gary and Fred M. Tileston. 1977. Irrigation: A Paradox for Sahelian Development. Washington, D.C.: Agency for International Development.

Nelson-Richard, S. M. 1981. "Experiment on Rural Development in an African State: Zambia/the Chunga Irrigation Scheme," Journal of African Studies, 8, 4, pp. 146-162.

Nelson-Richards, M. 1982. Social Change and Rural Development--Intervention or Participation, a Zambian Case Study. Washington, D. C.: University Press of America.

N'Diaye, M. 1980. Etudes des systèmes de production en cultures irriguée. Richard Toll, Dakar: ISRA, 16 pp. Mimeo.

Nesson, C., M. Rouvillois-Brigol, and J. Vallet. 1973. Oasis du Sahara Algérien. Etudes de Photo-Interpretation No. 6, Paris: Institut Géographique National.

Newman, M., I. Ouedraogo and D. Norman. 1980. "Farm-Level Studies in the Semi-Arid Tropics of West Africa," pp. 241-263. ICRISAT, Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. Pantancheru, India: ICRISAT.

Ng, Poh-Kok. 1986. "Irrigation Design: A Conceptual Framework," pp. 61-78. In, Hydraulics Research, Irrigation Design for Management, Asian Regional Syumposium (16-18 February 1987). Wallingford, England: Hydraulics Research.

Ng, Ronald. 1982. "Conceptual Framework for Designing, Monitoring and Evaluation System for Irrigation Projects." Washington, D.C.: World Bank, unpublished paper prepared in connection with the East Java Province Irrigaiton Projection (XVII) in Indonesia, 23 pp.

Ngana, James. 1985. "Experience of Irrigaiton Development in Dodoma Region: The Case of Ikowa Irrigation Scheme," pp. 73-105. In, Mascarenhas, A., et al. Opportunities for Irrigation Development in Tanzania. JRP Series, No. 52. Tokyo: Institute of Developing Economies.

Niagna, S. A. 1972. "Projet d'aménagement agricole du lac de Bam à Kongoussi, Haute Volta," Bulletin de l'institut panafricain pour le développement, No. 16, September, pp. 35-43.

Nicholas, Guy, Hubert Doumesche and Maman dan Mouche. 1968. Etude socio-économique de deux villages Hausa. Enquête en vue d'une aménagement hydro-agricole, vallée de Maradi (Niger). Niamey: IFAN/CNRS, Etudes Nigeriennes, No. 22, 257 pp.

Nicholas, Guy. 1971. "Processus de résistance au développement au sein d'une société Africaine (Vallée de Maradi)," Civilisations, Vol. XXI, No. 1, pp. 45-66.

Nicholson, S. E. 1981. "The Historical Climatology of Africa," Wigley, T. et al. (eds.). Climate and History. Cambridge: Cambridge University Press, pp. 249-270.

Nicholson, Sharon. 1982. The Sahel: A Climatic Perspective. Sahel (82) 187. Paris: Club du Sahel CILSS, OECD, 80 pp.

Nickell, Louis G. 1977. "Sugarcane," Alvim, Paulo de T. and T. T. Kozlowski (eds.) Ecophysiology of Tropical Crops New York: Academic Press.

Nicou, R. 1978. "Etude de successions culturales au Sénégal. Résultats et méthodes," L'Agromie Tropicale, No. 1, Jan-Mars. pp. 51-61.

Nicou, R. and C. Charréau. 1980. "Mechanical Impedance to Land Preparation as a Constraint to Food Production in the Tropics (with special reference to fine sandy soils in West Africa)." In: International Rice Research Institute, Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics. Manila: International Rice Research Institute.

Nieuwolt, S. 1977. Tropical Climatology: An Introduction to the Climates of the Low Latitudes. London: John Wiley & Sons.

Niger, République du. 1961. Aménagement hydro-agricole de Kolo, December. Paris: COGERAF, 21 pp.

Niger, République du. 1961. Note deméthode pour l'étude des investissements hydro-agricole au Niger, Décembre, Paris: COGERAF, 30 pp.

Niger, République du. 1964. Aménagement hydro-agricole de la cuvette de Karma: Projet d'études avant projet. Rome/Niamey: FAGARIA/Ministère d'économie rural, Génie Rurale, 2 Volumes.

Niger, République du, Commissariat General au Développement. 1971. Analyse des transformations socio-économiques dues à l'aménagement hydro-agricole d'une région Ibohamane/arrondissement de Keita, Ader Doutchi Maggia. Tahaoua: Commissariat Général au Developpement, Etudes et Programmes, Tahoua.

Niger, République du, Ministère de l'économie rural/Service du génie rural. 1972. Prospection hydro-agricole sur bordure de l'Air. A. Rapport. B. Propositions d'aménagements. Grenoble: SOGETHA.

Niger, République du, Ministère du Développement Rural, UNCC, Service de Production/Division de Gestion des Aménagements Hydro-agricole. 1976. lèr partie: Rapport d'activités 2ème partie: Rapport de passation de service. Niamey: Ministere du Développement Rural, 77 pp.

Niger, Républic du. 1981. ONAHA, Fiches Signaletiques, Niamey: ONAHA.

Niger, République du, Ministère du Plan. 1981. Les Aménagements Hydro-agricoles. Etude Comparative des coûts d'investissements et de fonctionnement. France: SOGREAH: Ingenieurs Conseils, 146 pp.

Niger, République du. ONAHA. 1982. Projet de réhabilitation des aménagement hydro-agricole au Niger. Périmètres de l'Ader-Doutchi Maggia. 2ème étape. Avant projet, sommaire et étude de préfactibilité. Grenoble: SOGREAH/Paris: Louis Berger, 3 Volumes.

Niger, République du. L'aménagement hydro-agricole de Firgoum. Paris: COGERAF.

Nighier, P. 1961. L'Afrique de l'ouest vue par un agricultueur. Paris: La maison rustique, 133 pp.

Nir, Dov. 1974. The Semi-Aird World: man on the fringe of the desert. London: Longman, 187 pp.

Njoku, Athanasius .O. 1971. "Labor Utilization in Traditional Agricuture: The Case of Sierra Leone Rice Farms." Ph.D. Thesis, University of Illinois at Urbana - Champaign, 206 pp.

Norman, David W., Simmons, Emmy B. and Hays, Henry M. 1982. Farming Systems in the Nigerian Savanna. Boulder, Colorado: Westview Press, 275 pp.

Noube, Elias, 1984. An Analysis of the Farming Perceptions of Small Farmers at Gwabhila and Silalabuhwa Scheme in Matebeleland, Zimbabwe. Ph.D. Thesis, Kansas State University, 180 pp.

Nweke, F. I. 1978. "Irrigation Development in Ghana: Needs, Potentials and Policy Issues," Oxford Agrarian Studies, 7, pp. 38-53. University of Nigeria: Department of Agricultural Economics.

Oad, Ramchand N. 1986. "Analysis of Engineering Aspects of Small-Scale Irrigation Systems,f" pp. 80-93. In, Coward, E. W., Jr. et al. Watering the Shamba. Ithaca, New York: Cornell University.

Oad, Ramchand. 1986. "Designing Irrigation Systems for Farmer Participation," pp. 21-33. In, Hydraulics Research, Irrigation Design for Management, Asian Regional Symposium (16-18 February 1987). Wallingford, England: Hydraulics Research.

O'Brien, J.J. 1980. Agricultural Labor and Development in Sudan. Ph.D. Thesis, University of Connecticut, 577 pp.

Obeid, Mohammed (ed.) 1975. Aquatic Weeds in the Sudan, with Special Reference to Water Hyacinth. Khartoum: National Council for Research jointly with National Academy of Sciences, USA.

Obeng, H.B. 1969. Provisional Soil Groups of Ghana. Kumasi: Council for Scientific and Industrial Research. (with provisional map at 1:1,000,000).

Obeng, L. 1977. "Should Dams be Built? The Volta Lake Example," Ambio, 6, 1, pp. 46-50.

Obeng, Letitia E. 1978. "Starvation or Bilharzia?--A Rural Development Dilema," pp. 343-351. Widstrand, Carl (ed.) The Social and Ecological Effects of Water Development in Developing Countries. New York: Pergamon Press.

OCDE. 1983. Principales conclusions du colloque du CAD sur l'aide à l'irrigation. Paris: Direction de la cooperation pour le développment, 15 pp.

OCDE. Rehabilitations régionales des systèmes d'irrigation dans la région du Sahel. Mandat d'exécution. Paris: OCDE, 20 pp.

OCDE. 1985. Management of Water Projects: Decision-Making and Investment Appraisal. Organization for Economic Cooperation and Development, Paris.

Oculi, Okello. 1981. Planning the Bakalori Irrigation Project, Food Policy, Aug. 1981, pp. 201-204.

Odell, R.T. and J.C. Dijkerman. 1967. Properties, Classification and Use of Tropical Soils with Special Reference to those in Sierra Leone. Njala University.

Oduolowu, A. 1977. "Qualitative Interpretation of Remotely Sensed Data as a Key to Mapping Vegetation Patterns in the Western Sudan," Geojournal, vol. 1, no. 5, pp. 13-20.

Oguntoyinbo, J. S. 1970. "Irrigation and Land Reclamation Projects in Nigeria," Nigerian Agricultural Journal, 7, 1, pp. 53-69.

Ojo, O. 1977. The Climates of West Africa. London: Heinneman.

Okereke, O. 1975. Agrarian Development Programmes of African Countries: A reappraisal of problems of Policy. University of Nigeria, Nsukka, Nigeria. Research Report, Scandinavian Institute of African Studies, Uppsala, Sweden, 20 pp, 2 tab, ref.

Okigbo, B. 1984. "Improved Permanent Production Systems as an Alternative to Shifting Intermittent Cultivation," pp. 1-100. In, FAO, Improved Production Systems as an Alternative to Shifting Cultivation, FAO Soils Bulletin, no. 53. Rome: FAO.

Okwuobi, P. A. C. 1979. "Irrigation Prospects in Bendel State of Nigeria," Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, 105, IR 1, pp. 99-106.

Olofin, E. A. 1982. "Some Effects of the Tiga Dam and Reservoir on the Downstream Environment on the Kano River Basin," Beitrage zur Hydrologie, 3, pp. 11-28.

Olsen, Edwin C. 1983. "On-Farm Water Management of Small Irrigated Perimeters, USAID/Mali." Logan, Utah: International Irrigation Center (unpublished paper), 18 pp.

Oluwasanmi, H. A. Dema, et al. 1966. Uboma: A Socio Economic and Nutritional Survey of a Rural Community in Eastern Nigeria. Bude, U. K.: Geographical Publications, Ltd.

Omar, M. S. and Aziz, 1983. "The Effect of Soil Moisture Depletion on Wheat Production," Egyptian Journal of Science 23(1) pp. 1-7.

O'Mara, Gerald T. 1984. Issues in the Efficient Use of Surface and Groundwater in Irrigation. World Bank Staff Working Papers, No. 707. Washington, D. C.: World Bank, 93 pp.

OMVS. 1971. Aménagement et mise en valeur du bassin du fleuve Sénégal. Saint-Louis, Senegal: OMVS Documentation Center.

OMVS. 1976. Aménagement du bassin versant du fleuve Sénégal. Dakar: OMVS.

OMVS. 1977. Elements de facibilité du barrage de Diama. Dakar: OMVS.

OMVS. 1977. Périmètres d'Irrigation sur la Rive Gauche du fleuve Senegal. Dakar: OMVS.

OMVS. 1980. Etude Socio-Economique de l'OMVS. Dakar: OMVS. 5 Vols.

OMVS. 1980. Interpretation of Results and Recommendations in the Field of Rural Development. General Report, Part E: Social and Economic Study of the Senegal River Basin. Saint Louis: OMVS.

OMVS. Evaluation des éffets sur l'environnement prévus dans le bassin du fleuve Sénégal. Harrisburg: Gannet and Flemming.

OMVS. Etude socio-économique de l'OMVS. Dakar: OMVS., 5 Volumes.

Ongwenyi, George S. 1985. "Problems of Land Use and Water Resources Management in the Upper Tana Catchment in Kenya," pp. 123-130. In, Lundqvist, Jan, et al. (eds.) Strategies for River Basin Management. Dordrecht, the Netherlands: D. Reidel.

Ooman, J.M.V. 1981. Monitoring Health in African Dams: The Kamburu Dam (Kenya) as a Test Case. Thesis, Erasmus University, Rotterdam, 181 pp.

Oosterbahn, R. J. 1982. "Natural and Social Constraints to Polder Development in Guinea-Bissau," Polders of the World, Volume 1, Wageningen, Netherlands: International Institute for Land Reclamation and Improvement, pp. 146-160.

Opio-Odongo, J. M. A. 1975. "Agricultural Productivity in Uganda: A Social Organisational Perspective." Cornell University, Ithaca, New York, USA. Eastern Africa Journal of Rural Development, Vol. 8, No 1/2, 1975, pp. 118-128.

O'Reilly, F. D. 1980. "Large Scale Irrigation Projects and Small African Farmers." Paper presented for ASAUK/IBG Conference: Recent Change in Development Theory and Africa. University of Manchester.

O'Reilly, F. D. 1983. "Traditional Management of Rice Cultivation in the Sokoto-Rima Irrigation Area. (N. W. Nigeria)." Unpublished paper: ODI Lunchtime Seminar Series.

ORSTOM. 1966. Bibliographie hydrologique: liste des rapports et publications hydrologiques de 1948 à 1966. Paris: ORSTOM.

ORSTOM. 1967. Service hydrologique. Monographie hydrologique du Logone. Paris: ORSTOM/ Ministère de la Coopération, 129 pp.

ORSTOM. 1968-69. Monographie hydrologique du Chari. Paris: ORSTOM, 5 Vols.

ORSTOM. 1969. Techniques rurales en Afrique. Paris: SEAE, 211 pp.

ORSTOM. 1969. Monographie hydrologique du Chari 1er partie: Facteur conditionnels du régime. Paris: ORSTOM, 114 pp.

ORSTOM. 1969. Liste des rapports et publications hydrologiques de 1967 à 1969. Paris: ORSTOM.

ORSTOM. 1975. Service Hydrologique. Détermination des causes des crues du Niger (Mali). --Rapport de la première année d'études sur les anomalies. --Remise en état du réseau hydrometrique au Mali. Rapport d'activités et Annuaire. Paris: ORSTOM, 2 Vols.

ORSTOM. 1979. Maitrise de l'espace agraire et développement en Afrique Tropicale. Actes du Colloque du Ouagadougou. Paris: ORSTOM, 600 pp.

ORSTOM. 1979. Monographie hydrologique du Bassin du Niger. Paris: ORSTOM, 3 Vols.

Oredal, A.C. 1975. Bibliography of Soils of the Tropics: Vol. I. Tropics in General and Africa. Washington, D.C.: Technical Series Bulletin No. 17, Office of Agriculture, Agency for International Development.

Osman, M. Shazali and El Haq, H.E. 1974. "Irrigation Practices and Development in the Sudan," Sudan Notes and Records, vol. 55, pp. 96-110.

Othieno, C. O. 1982. "Supplementary Irrigation of Young Clonal Tea in Kenya. III. Comparative Dry Matter Production and Partition," Tea, 3, 1, pp. 15-25.

Oudin, Patric. 1974. Les jardins du Bas-Teloua, République du Niger: travail d'étude et de recherche. Grenoble: Université de Grenoble.

Ouedraggo, Ouendkouni. 1978. Etude des aménagements hydro-agricoles et des déplacements de populations en Afrique de l'Ouest: l'examPle de la Haute Volta de 1900 à nos jours. These, Doctorat d'Etat, Université de Bordeaux III, inscript. No. 3685, rep de theses 78.

Ouedraggo, D. 1979. "La Vallée du Kou (Haute Volta): un Sous-Espace Aliene," Maitrise de L'Espace Agraire et Développement en Afrique Tropical, pp. 481-490. Paris: ORSTOM.

Ouedraggo, I. et al. 1982. The Farmer in the Semi-arid Tropics of West Africa. ICRISAT Research Bulletin No. 4, Vol. 2. Hyderabad; Andhra Pradesh, India: International Crops Research in the Semi-Arid Tropics.

Ouldeli, Brenot. 1980. Demography of the Sahel Countries. Current situation and long term perspectives. Paris: Club du Sahel/ CILSS, OECD, 97 pp.

Over, A. Mead, Jr. 1983. On the Care and Feeding of a Gift Horse: The Recurrent Cost Problem as the Result of Biased Project Design. Africa Studies Center Working Papers, No. 69. Boston: Boston University, 32 pp.

Overseas Development Institute. 1976. " Mwea: an Irrigated Rice Settlement in Kenya." Paper C1, ODI Workshop on Choices in Irrigation Management. 27 Sept - 1 Oct. 1976.

Owen, D.F. 1973. Man in Tropical Africa: the Environmental Predicament. London: Oxford University Press, 214 pp.

Pacey, Arnold. 1977. Hand Pump Maintenance in the Context of Community Projects. Oxford-London, 38 pp.

Packard, R. M. 1986. "Agricultural Development, Migrant Labor and the Resurgence of Malaria in Swaziland," Social Change & Medicine, vol. 22, no. 8. pp. 186-867.

Page, John M., Jr., and J. Dirck Stryker. 1981. "Appendix A - Methodology for Estimating Comparative Costs and Incentives," pp. 435-454. In: Pearson, Scott R., J. Dirck Stryker, Charles P. Humprheys, et al, Rice in West Africa. Stanford, California: Stanford University Press.

Pallier, Ginette. 1975. "Un étude de cultures maraîchères en zone soudano-sahielienne; les jardins du lac de Bam en Haute Volta," Les Cahiers d'Outre Mer, No. 111, juillet-septembre 1975, pp. 252-274.

Palmer-Jones, R. W. 1977. "Irrigation System Operating Policies for Mature Tea in Malawi," Water Resources Research, 13, 1, pp. 1-7.

Palmer-Jones, R. 1981. "How Not to Learn from Pilot Irrigation Projects: The Nigerian Experience," Water Supply and Management, Vol. 5, No. 1.

Palmer-Jones, R. W. 1983. "Mismanaging the Peasants: Some Origins of Low Productivity on Irrigation Schemes in the North of Nigeria," Grove, A. T., and Adams, W. M. (eds.).Irrigation in Africa: Problems and Problem Solving Cambridge, England: African Studies Centre, University of Cambridge.

Palutikof, J.F. 1981. "Irrigation in Semi-Arid Areas," pp. 66-83. In, Campbell, David and Migot-Adholla, S. (eds.) The Development of Kenya's Semi-Arid Lands. IDS Occasional Paper No. 36. Nairobi: Institute for Development Studies, University of Nairobi.

Pantulu, V. R. 1985. "Ecosystem Modelling of a River Basin," pp. 31-40. In, Lundqvist, Jan, et al. (eds.) Strategies for River Basin Management. Dordrecht, the Netherlands: D. Reidel.

Papadakis, J. 1966. Enquête Agro-écologique en Afrique occidentale. Texte anglais et français. Rome: FAO., 103 pp.

Papadakis, J. 1975. Climates of the World and their Potentialities. Buenos Aires: Libio de Edicion Argentina.

Pare, Jaques. 1973. "La lutte contre l'érosion dans les aménagements agricoles," Techniques et Développments, No. 8, Juillet-août, pp. 36-39.

Park, Thomas K. 1986. "Mauritania: Senegal River Valley," pp. 52-73. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, University of Wisconsin-Madison.

Parnell, Theodore and Albert E. Utton. 1976. "The Senegal Valley Authority: A Unique Experiment in International River Basin Planning." Indiana Law Journal. Vol. 52, No. 2, pp. 235-256.

Parry, Georges. 1982. Le Cotonnier et ses Produits. Paris: G. P. Maisonneuve et Larose.

Pascon, P. 1983. "La petite et moyenne hydraulique au Maroc, Problèmes institutionals et juridiques posés par son extension en Maroc." Colloque International Développement agricole et participation paysanne, un example: Les politiques de l'eau. University of Paris, 14-15 October 1983.

Pasternak, Burton. 1968. "Social Consequences of Equalizing Irrigation Access." Human Organization, Vol. 27, No. 4 pp. 332-343.

Patterson, William McClinton. 1984. Village Irrigation Systems Along the Senegal River: A Comparative Analysis. Ph.D. Dissertation, Cornell University, Ithaca, New York, 135 pp.

Paul-Emile, M. and A. Bartlet. "Un puits dans chaques village," Ceres, No. 42, Nov-Dec, pp. 47-49.

Paulissen, Van Doorn. 1977. L'énergie eolienne dans le Sahel. Etude préliminaire sur les possibilities d'utilisé l'energie Eolienne pour le pompage de l'eau dans le Sahel. Dakar: Club du Sahel, 29 pp.

Paulson, R.W. and W.G. Shope. 1985. "Development of Earth Satellite Technology for the Telemetry of Hydrologic Data," Water Resources Journal (December), pp. 10-17.

Payer, Cheryl. 1982. "Water Resources," pp. 246-287. In, The World Bank: A Critical Analysis. New York: Monthly Review Press.

Paylore, Patricia. 1976. Desertification: A World Bibliography. Tucson, Arizona: Office of Arid Land Studies, Univ. of Arizona, 271 pp.

Pearce, E. A. and C. G. Smith. 1984. The World Weather Guide. London: Hutchinson.

Pearce, R. P. (ed.). 1981. "Tropical Droughts: Meteorological Aspects and Implications for Agriculture." Papers presented at the WMO Symposium on Meteorological Aspects of Tropical Meteorology, New Delhi, 7-11 December 1981. Geneva: World Meteorological Organisation.

Pearson, M. 1980. Settlement of Pastoral Nomads: A Case Study of the New Halfa Irrigation Scheme, University of East Anglia: Development Studies Occasional Paper, No. 5, 60 pp. University of East Anglia.

Pearson, Scott R., J. Dirck Stryker, and Charles P. Humphreys. 1981. Rice in West Africa: Policy and Economics. Stanford: Stanford Univ. Press, 482 pp.

Pech, R.P., et al. 1986. "Calibration of LANDSAT data for sparsely vegetated semi-arid rangelands," International Journal of Remote Sensing, vol. 7, no. 17, pp. 1729-1750.

Pelissier, P. and S. Diarra. 1978. "Traditional Strategies, Modern Decision-making and Management of Natural Resources in Sudan Africa," UNESCO, Management of Natural Resources in Africa: Traditional Strategies and Modern Decision-making. MAB Technical Note 9. Paris: UNESCO, pp. 36-55.

Penning de Vries, F.W.T. and Djitèye, M.A. (eds.) 1982. La Productivité des Pâturages Sahéliens. Wageningen: PUDUC.

Penning de Vries, F. W. T. 1983. "The Productivity of Sahelian Rangelands--A Summary Report," ODI Pastoral Network Paper 15 b. London: Overseas Development Institute, 31 pp.

Pereira, H. C. 1973. Land Use and Water Resources. Cambridge, U.K.: Cambridge University Press.

Perera, N.P. 1982. "The Ecology of Wetlands (dambos) of Zambia, and Their Evaluation for Agriculture - A Model for the Management of Wetlands in Sub-Humid Eastern and Southern Africa". International Journal of Ecology and Environmental Sciences, 8(1):27-38.

Perraud, A. and P. de la Souchere. 1966. Esquisse pédologique de la Cote-d'Ivory. (with 4 maps at 1:500,000) Abidjan: ORSTOM.

Peter, Dominique et al. 1979. Development of Irrigated Agriculture in The Gambia: General Overview and Prospects Proposals for a Second Programme 1980-85. Paris: CILSS/Club du Sahel for Republic of The Gambia (Sahel D (79)48), 60 pp.

Peter, Jean E. 1976. "La situation et les perspectives d'aménagement des vallées de voltas," Afrique Agriculture, No. 14, October, pp. 48-51.

Peter, J. E. 1978. Le dossier Sahel. Tome 2: L'irrigation et l'autosuffisance alimentaire à l'horizon 2000. Paris, France: EDIENA.

Peterson, Dean F. "Systems and Technology for Improved Irrigation Water Management," Paper for Agriculture and Rural Development Training Workshop, Washington D.C., 18-22 June, 1984, 24 pp.

Philippon, B. and J. Mouchet. 1976. "Répercussion des aménagements hydrauliques à usage agricole sur l'épidemologie des maladies à vecteurs en Afrique intertropicale," Colloque. Paris: CENECA.

Phillips, John. 1959. Agriculture and Ecology in Africa. New York: Frederick A. Praeger.

Phillips, John. 1967. The Development of Agriculture and Forestry in the Tropics. New York: Frederick A. Praeger, Inc.

Phillips, Lucie Colvin. 1986. "Madagascar: The Central Highlands," pp. 116-125. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, Unviersity of Wisconsin-Madison.

Phillips, Lucie Colvin. 1986. "Sudan: Northern Province," pp. 74-83. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, Unviersity of Wisconsin-Madison.

Pias, J. 1968. Carte pédologique du Tchad au 1:1,000,000. Fort-Lamy: ORSTOM.

Pieri, D. 1970. Rapport pédologique Fana. (with map at 1:100,000) Bamako: IRAT.

Pilditch, A. G. and G. J. Wilson. 1978. "Irrigation Systems used for Coffee," Rhodesian Agricultural Journal, vol. 75, no. 5, pp. 123-124.

Pimentel, David and Pimentel, Marcia. 1979. Food, Energy, and Society. London: Edward Arnold, 165 pp.

Plassan, Jacques. 1982. "Systêmes de culture et structures agraires dans les campagnes Sénégalaises," Cahier du Centre de développment de lUniversité de Rennes, No. 1.

Platon, P. 1981. "La mise en valeur du bassin du fleuve Sénégal," Marchés Tropicaux et Mediterranéens, 37, 1849, pp. 106-1099.

Plusquellec, H. L. 1983. "Land Consolidation in Irrigation Projects," Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, 109, I, pp. 99-110.

Plusquellec, H. L. and Thomas Wickham. 1985. Irrigation Design and Management: Experience in Thailand and its General Applicability. World Bank Technical Paper No. 40. Washington, D.C.: The World Bank, 76 pp.

PNUD. 1977. Aménagement du bassin du fleuve Gambie. Mission multi-disciplinaire, multi-donateurs. Mars-Avril 1977. Programme d'action, 2 Volumes. New York, PNUD.

PNUD. 1979. Etude du dévelopment du Bassin du Lac Tchad: Rapport final, 4 Volumes. Paris: ORSTROM/SOGREAH/ Ministère de la Coopération.

Podmore, C.A., (Ed.). 1983. Diagnostic Analysis for Irrigation Systems, volume I: Concepts and Methodology. Water Management Synthesis Project, Colorado State University, Fort Collins, CO.

Poisson, C. 1981. "Introduction de la Culture du Blé en Haute-Volta (Résultats Acquis de l'Experimentation en 1979)," Agronomie Tropicale, Vol. 36, No. 1, pp. 54-62.

Pollard, Nigel. 1981. "The Gezira Scheme--A Study of Failure." The Ecologist, (Jan.-Feb.), Vol. 11, No. 1, pp. 21-31; emphasizes aggregate negative impacts, particularly upon health.

Posny, Pierre, Jean Pietri, and Rene Perronnet. 1977. Etudes des problèmes relatifs à la création d'un ONAHA; Rapport de mission. Paris: Ministère de la Coopération; Niamey: Ministère du Développement Rural, 93 pp.

Posny, P. 1979. The Development of Irrigated Agriculture in Niger. General Overview and Prospects. Proposals for a Second Programme 1980-85. Ougadougou: Upper Volta; CILSS/Club du Sahel.

Post, W. S. 1982. A Short Review of Irrigation Development in General and Small-Scale Irrigation in Particular. Prepared for the Small-Scale Irrigation in Africa meeting, held in Rome (FAO) 16-19 Nov 1982.

Post, W. S. The Role of Minor Irrigation Projects in Rural Community Development; Their Charcteristics and Organizational Set-Up. (Unpublished paper, circa 1983.)

Potten, David. 1984. "Irrigation in Madagascar: a Brief Review," pp. 14-19. In, Adams, W. M. and Grove, A. T. (eds.) Irrigation in Tropical Africa. Cambridge African Monographs, No. 3. Cambridge, England: African Studies Centre, Cambridge University.

Poulain, J. F. 1976. "Amelioration de la fertilité des sols agricole du Mali; Bilan de treize ans de travaux (1962-74)," Agronomie Tropicale, Vol. 31, No. 4, pp. 403-416.

Prashar, C. R. K. 1981. "Water Management Strategy Under Limited Water Supply Conditions." (Abstract) 73rd Annual Meeting, American Society of Agronomy, Madison, Wisconsin: American Society of Agronomy.

PRC (Nigeria) Ltd. 1982. A Study of Cost Recovery Strategy for Irrigaiton Projects, Final Report. Lagos: PRC (Nigeria) Ltd. with Ibadan University Consulting Services for the Federal Ministry of Water Resources.

Price, Mark. 1981. "The Rangelands: Pastoralism and Ranching," pp. 150-175. In, Campbell, David and Migot-Adholla, S. (eds.) The Development of Kenya's Semi-Arid Lands. IDS Occasional Paper No. 36. Nairobi: Institute for Development Studies, University of Nairobi.

Pritchard, John. 1979. Africa. London: Longman.

Prosser, A. R. G. 1982. "Community Development: The British Experience," Jones, Gwyn E. and Rolls, Maurice (eds.) Progress in Rural Extension and Community Development John Wiley.

Prowde, O. L. 1928. The Gezira Irrigation Scheme, Including the Sennar Dam on the Blue Nile. Proceedings of the Institute of Civil Engineers, London, Vol. 228 (1928- 29), 81 pp.

Pullan, R. A. 1969. "The Soil Resources of West Africa," pp. 147-191. In, Thomas, M. F. and Whittington, G. W. (eds.) Environment and Land Use in Africa. London: Methuen.

Purdue University, Department of Agricultural Economics. 1978. Costs and Returns of Sorghum and Millet Production and Costs and Benefits from Small and Medium Sized Irrigated Perimeters in the Sahelian Countries; Semi-Annual Report. West Lafayette, Indiana: Purdue University.

Purdue University, Department of Agricultural Economics. 1978. Semi-Annual Report, Purdue/AID Contracts AID/AFR C-1257 and 1258 West Lafayette, Indiana: Purdue University.

Purseglove, J. W. 1968. Tropical Crops--Dicotyledons. New York: Halstead Press, John Wiley and Sons.

Purseglove, J. W. 1972. Tropical Crops--Monocotyledons. New York: Halstead Press, John Wiley and Sons.

Quantin, P. 1965. Les sols de la République Centrafricaine. (with map at 1:5,000,000) Paris: ORSTOM.

Rabochev, I. S. and I. G. Samarets. 1981. "Soil Ameliorative Grouping of Libyan Lands According to their Suitability for use for Irrigation Agriculture," Problems of Desert Development, No. 2, pp. 56-64.

Rachie, Kenneth O. and Majmudar, J.V. 1980. Pearl Millet. University Park, PA: Pennsylvania State University Press, 307 pp.

Rafols, W. de. 1982. Economic Analysis Update, (unpublished report). Bamako: USAID/Mali. 37 pp.

Raikes, P. 1968. Prospects for Exports of Tanzanian Agricultural Produce to Zambia. Mimeograph, Economic Research Bureau, University College, Dar es Salaam, Tanzania.

Raimondo, Pasquale. 1978. "L'aménagement hydro-agricole de Toula," Le Courrier, No. 47, Janvier-Février, pp. 83-84.

Rakoto-Ramiarantsoa, H. 1983. "Développement à Contre-Sens: Un Aménagement Hydro-Agricole qui n'a pas donne les Résultats Escompts. Réseau Hydro-Agricole du PC 23 Bird, curette du Lac Alaotra (Madagascar)." Paper pre-sented for the International Conference: Développement agricole et participation paysanne. Un exemple: Les politiques de l'eau en Afrique. University of Paris I, Centre d'Études Juridiques Comparatives.

Ramaer, R. 1973. "Les lacs, artificiels et leurs conséquences dans le développement de l'Afrique," Bulletin du Poste Scientifique, Vol. 8, No. 1, Jan.-Mar. 1972, pp. 36-39.

Ramamonjisoa, J. 1983. "Les aménagements Malgaches dans le domaine des aménagements rizicoles. Colloques International: Développement agricole et participation paysanne. Une exemple: Les politiques de l'eau. Université de Paris, 14-15 October, 1983.

RAMS Project. Rural Assessment and Manpower Surveys, SS-1, Irrigated Agriculture. (Undated).

Rangeley, W. Robert. 1985. "Irrigation in Arid Africa; Contribution and Issues," Paper for the World Bank Second Irrigation and Drainage Seminar, Annapolis, Maryland, December 17-19, 1985. Washington, D.C.: The World Bank, 24 pp.

Rapp, Anders. 1975. "Soil erosion and sedimentation in Tanzania and Lesotho." Ambio. 4(4):154-163.

Rasool, S. I. 1984. "On Dynamics of Desert and Climate," Houghton, J. T. (ed.). The Global Climate Cambridge University Press (op cit.), pp. 107-120.

Raulin, Henri. 1965. "Travail et régimes foncier du Niger," Cahiers de l'ISEA, No. 166, Serie V, pp. 119-139.

Raulin, Henri. 1967. La dynamique des techniques agraires en Afrique tropical du nord. Paris: CNRS, 267 pp.

Raulin, Henri. 1976. "Organized Cooperation, a Spontaneous Cooperation in Africa (Niger Republic)," Popular Participation in Social Change, June Nash et. al. ed. The Hague: Mouton, pp. 35-43.

Raunet, M. 1980. "La Plaine Cotière de Djibouti: morphologie et recherche de périmètre irrigable en zone aride," Agronomie Tropicale, Vol. 35, No. 4, pp. 335-352.

Ravignan, Francois de. 1976. "Niger: cultures traditionelles et périmètres irrigués, comment augmenter la prodution céréalier," Le Monde Diplomatique, No. 270, septembre, p. 14.

Raynaud, C. Organisation régionale de développement, Haute Volta: Cellule vulgarisation; opération riz.: fiches techniques. Ouagadougou: Ministère de Développement Rural, 2 Volumes.

Raynaut, C. 1977. "Circulation monetaire et evolution des structures socio-economique chez les Haoussas du Niger," Africa, Vol. 47, No. 2, pp. 160-71.

Raynaut, Claude. 1969. Quelques données de l'horticulture dans la vallée de Maradi. Niamey: IFAN/CNRS, Etudes Nigeriennes, No. 26, 164 pp.

Raza, M.R. and Y.A. Abdullahi. 1979. "Irrigation Schemes and the Agrarian Structure: A Respecification of the Impact of Landholding and Land use Patterns on Agricultural Development". Sixth National Irrigation Seminar. Zaria: Ahmadu Bello University, pp. 216-227.

Regional Inspector General for Audit. 1981. Major Implementation Problems Confront Project Action Blé in Mali. Washington, D.C.: U.S. Inspector General.

Reisman, Paul. 1980. "The Fulani in a Development Context," pp. 71-186. Reyna, Stephen P. (ed.) Sahelian Social Development. Abidjan: REDSO/USAID West Africa.

Reynaut, E. 1969. "Quelques Donées de l'Horticulture dans la Vallée Maradi." Etudes Nigériennes, No. 26, pp. 1-164.

Richards, Paul. 1985. Indigenous Agricultural Revolution. Ecology and Food Production in West Africa. London: Hutchinson, 192 pp.

Richards, Paul. 1986. Coping with Hunger: Hazard and Experiment in an African Rice-Farming System. London: Allen & Unwin, 176 pp.

Riddell, James C. 1986. "Kenya," pp. 84-95. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, University of Wisconsin-Madison.

Riddell, James C. 1986. "Mali: Niger River Basin," pp. 42-51. In Bloch, Peter, et al. Land Tenure Issues in River Basin Development in Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, University of Wisconsin-Madison.

Riggs, H. C. 1979. "Inventorying Streamflows in Areas of Low precipitation," International Association of Scientific Hydrology. The Hydrology of Areas of Low Precipitation, pp. 151-158.

Riise, U. 1971. "Rainfall Variations in Tanzania," BRALUP Research Report, 45/1. Bureau of Resource Assessment and Land Use Planning, Dar es Salaam, Tanzania.

Riquier, J. 1968. Carte pédologique de Madagascar. (3 sheets at 1:1,000,000). Tananarive: ORSTOM.

Rivnay, E. 1972. "On Irrigation-Induced Changes in Insect Populations in Israel." In: Farvar, M.T. and John P. Milton. The Careless Technology; Ecology and International Development. Garden City: The Natural History Press.

Robertson, A. C. 1950. The Hafir--What, Why, Where, and How, Bulletin No. 1, Khartoum: Ministry of Agriculture, Sudan Government, Information for identification and excavation of appropriate areas for hafirs (storage tanks).

Robinson, J. C. 1979. "Note on Irrigation of Subtropical Fruit Trees," Hortus, No. 26, 28-29 pp.

Rochette, C. and P. Touchebeuf. 1964. Aperçu-hydroagricole du fleuve Sénégal. Paris: ORSTOM, 67 pp.

Rochette, C. 1974. Le Bassin du fleuve Sénégal. Paris: ORSTOM, Monographies Hydrologiques.

Rochette, R. 1965. "Au Niger, Kawara-Debe village de mares," Revue Géographique Alpine, Vol. 53, No. 2, pp. 169-203.

Rodda, J. 1971. "Report on Precipitation," Bulletin of the International Association of Scientific Hydrology, 16(4), pp. 37-39.

Roder, Wolf. 1965. The Sabi Valley Irrigation Projects. Dept. of Geography Research Paper No. 99. Chicago: University of Chicago, 213 pp.

Rodier, J. 1963. "Hydrology in Africa," UNESCO, pp. 179-220.

Rodier, J. 1963. Bibliography of African Hydrology. UNESCO: Paris.

Rodier, J. 1964. Regimes hydrologiques de l'Afrique noire à l'ouest du Congo. Paris: ORSTOM, 139 pp.

Rodier, J.A. 1975. Evaluation de l'Ecoulement Annuel Dans le Sahel Tropical Africain. Paris: Office de la Recherche Scientifique et Technique Outre-Mer.

Roe, Emery. 1980. Development of Livestock, Agriculture and Water Supplies in Eastern Botswana Before Independence: A Short History and Policy Analysis. (Cornell University, Rural Development Committee, Occasional Paper No. 10.) Ithaca, New York: Cornell University.

Roe, Emery and Fortman, Louise. 1982. Season and strategy: Organization of the Rural Water Sector in Botswana. The Changing Development Committee, Center for International Studies, Cornell University, 264 pp.

Roe, J.D.M. and Whitaker, M.J. 1985. "Management Practices and Coffee Productivity within the Estate Sector," Kenya Coffee, vol. 650, no. 585, pp. 325-345.

Rolland, Lionel. 1982. Mechanized Sprinkler Irrigation. Irrigation and Drainage Paper No. 35. Rome: FAO, 409 pp. Covers all aspects of sprinkler irrigation, bibliography (pp. 399-409).

Roorda Van Eysinga, S. N. P., S. Navez, and L. Dieng. 1974. Notes sur quelques problèmes du maraîchage traditionnel au Cap Vert. Dakar: Ministère du développement rural et de hydraulique, 44 pp.

Roose, Eric. 1977. Erosion et ruissellement en Afrique de l'Quest. Vingt années de mesures en petites parcelles expérimentales. Paris: ORSTOM., 108 pp.

Ross, Clark G. 1983. A Program for Foodgrain Self-Sufficiency in the Sahel by the Year 2000. A summary paper submitted to the Fifth Conference of the Club du Sahel, Brussels, by the U.S. Agency for International Development.

Roussin, J. P. 1974. Aspects juridiques des problèmes de l'eau dans les états membres du Comité Inter-Africains d'etudes hydrauliques (These). Université de Grenoble II.

Rossin, M. L. Bugeat, and C. de Casso. 1975. Elements pour l'établissement d'un schème directeur d'aménagement du Bassin du Niger. Paris: Ministère de la Coopération--BDPA, 36 pp.

Rossin, Maurice. 1976. "L'Office du Niger, un vieil aménagement plein d'avenir," Actuel Développement, No. 11, Jan-Fev, pp. 18-24.

Roussel, P. 1966. Guide des eaux souterraines de Mauritanie. Noukchott: Bureau hydrogéologique, 69 pp.

Rouvet, J. C. 1980. "Les critères pris en compte pour la localisation des périmètres irriguées villageois en Mauritanie," Périmètre irrigués villageois: Seminaire tenu a Dakar du 21 au 23 avril 1980. Paris: SATEC, pp. 6-21.

Rowling, C. W. 1952. "An Analysis of Factors Effecting Changes in Land Tenure in Africa," Journal of African Administration, Special Supplement, October.

Roy, Sumit. 1983. "The State and Large Scale Irrigation. Some Notes Based on Large-Scale Irrigation in Kano." Paper presented to the Centre for Social and Economic Research, Ahmadu Bello University, Zaria. June.

Ruche, J. 1974. Développement agricole au Niger: cultures irriguées ou cultures pluviales. Paris: Institut National Agronomique These doctorat du troisième cycle, Université de Paris I.

Rudloff, W. 1981. World Climates, with Tables of Climatic Data and Practical Suggestions. Stuttgart: Wissenschaftliche Verlalsgesellshhaft mbH.

Ruigu, G.M., P.O. Alila, and P.A. Chitere. 1984. A Social and Economic Survey, Bura Irrigation Settlement Project. Nairobi: Institute for Development Studies.

Rule, Ian. 1984. "Designing for Easy Maintenance," ODI Irrigation Management Network Paper, no. 10d. London: Overseas Development Institute, 4 pp.

Rural Development Unit. 1979. Agricultural Policies of the Five Entente Countries. Abidjan: Rural Development Unit, Ivory coast, 227 pp.; review of Niger, pp. 127-167.

Russell, J. R. 1928. Sluices and Machinery of the Gezira Irrigation Scheme. Proceedings of the Institute of Civil Engineers, London, Vol. 227 (1928-29), 95 pp.

Russell, T. P. J. 1971. Dambo Utilisation Survey. Lilongwe Land Development Project, Malawi.

Ruthenburg, H. 1980. Farming Systems in the Tropics. Oxford: Clarendon Press. [Third Edition].

Rydzewski, J.R. 1974. Irrigation Development in Africa South of the Sahara. Southampton, England: University of Southampton.

Saenger, P., E.J. Hegerl and J.D.S. Davie, eds. 1983. Global Status of Mangrove Ecosystems. (Commission on Ecology Papers No. 3.) By the Working Group on Mangrove Ecosystems of the IUCN Commission on Ecology. The Netherlands: International Union for Conservation of Nature and Natural Resources.

SAFEGE. 1980. Barrage de Tossaye sur le fleuve Niger: Reconnaisance détaillé du site Campagne 1979--Dossier géologique et géophysique. Nanterre: Direction Générale de l'Hydraulique et de l'Energie, 63 pp.

Sagardoy, J. A., A. Bottrall, and G. D. Uittenbogaard, 1982. Organisation, Operation and Maintenance of Irrigation Schemes. FAO Irrigation and Drainage Paper 40. Rome, Italy: Food and Agriculture Organisation.

Saha, Suranjit K. and Barrow, C.J. (eds.). 1981. River Basin Planning: Theory and Practice. Chichester, England: John Wiley, 367 pp.

Saha, S. K. 1982. "Irrigation Planning in the Tana Basin of Kenya. Centre for Development Studies, University College, Swansea, UK." Water Supply and Management, 6, 3, pp. 261-279.

Sahel Documentation Center. 1977 onwards. Sahel Bibliographic Bulletin. East Lansing, Mich.: Sahel Documentation Center.

Salam, M. M. Abdel. 1979. The Institutional Development of the Sudan Gezira Scheme with Special Reference to the Impact on Tenant's Performance. University of Reading, UK: Ph. D. Thesis.

Salam, M. M. Abdel. 1982. "Some Developmental Issues of Settlement Schemes in the Sudan: The Case of Es-Suki," DERAP Working Paper A 260. Bergen, Norway: CHR. Michelsen Institute.

Salem-Murdock, M. 1979. The Impact of Agricultural Development on a Pastoral Society: The Shukriya of Eastern Sudan. Binghamton, New York: Department of Anthropology, State University of New York at Binghamton for AID, Washington.

Salem-Murdock, M. 1984. "Nubian Farmers and Arab Herders in Irrigated Agriculture in the Sudan: From Domestic to Commodity Production." Ph.D. dissertation, SUNY-Binghamton, New York.

Salih, A. M. A. 1978. Irrigation and Water Resources in Sudan. Proc. International Conference on Water Resources Engineering, Bangkok, Thailand, 10-13 January 1978. Vol II, pp. 1025-1040.

Salih, Hassan Mohammed. 1985. "The Gash Delta: Labour Organization in Pastoral Economy versus Labour Requirements in Agricultural Production," pp. 2382-296. In, Clarke, Joh, et al. (eds.) Population and Development Projects in Africa. Cambridge, England: Cambridge University Press.

Sall, Alioune. 1977. "Transformations sociales dans une banlieue maraîchère, l'example de M'Bidieum," Environnement Africain, No. 77-21, December 1977.

Sanchez, P.A. and T. T. Cochrane. 1980. "Soil Constraints in Relation to Major Farming Systems of Tropical America." In: Soil-Related Constraints to Food Production in the Tropics, Manila, Philippines: IRRI.

Sanchez, Pedro A. 1976. Properties and Management of Soils in the Tropics. New York: Wiley Interscience.

Sanchez, P. A. 1980. "L'experience de petits périmètres Sénégal--Zone de Matam," Pêrimètre irrigués vil-lageois: Seminaire tenu à Dakar du 21 au 23 avril 1980. Paris: SATEC, pp. 38-47.

Sandberg, Audun. 1974. The Impact of the Stiegler's Gorge Dam on Rufiji Flood Plain Agriculture. BRALUP Service Paper no 74/2. Dar es Salaam: Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam.

Sandford, Stephen. 1983. Organisation and Management of Water Supplies in Tropical Africa, ILCA Research Report No. 8, Addis Ababa, Ethiopia: International Livestock Centre for Africa.

Saouma, E. 1981. "A New Food Order for Africa," Ceres 14(5), pp. 22-26.

Sapin, P. 1980. "Le Blé au Mali," Agronomie Tropicale, Vol. 35, No. 2, pp. 157-169.

SATEC. 1968. Programme du développement de la riziculture dans le delta du fleuve Sénégal. Paris: SATEC, 4 Volumes.

SATEC. 1975. Etude de reconnaissance de la vallée du Niger dans la région de Gao. Paris: SATEC.

SATEC. 1975. Irrigation par pompage au Sahel; les péri-mètres villageois: compte rendu de la séance de travail du 10 avril 1975. Paris: SATEC.

SATEC. 1976. Projet d'extension des périmètres villageois irriguées le long du fleuve Chari (Tchad). Paris: SATEC, 109 pp.

SATEC. 1980. Périmètres irrigué villageois. Seminaire tenu à Dakar du 21 au 23 avril 1980. Paris: SATEC.

SATEC. 1981. Périmètres irrigués villageois en Afrique Sahelienne. Paris: SATEC, 12 pp.

Sautter, G. and Mondjannagni. 1978. Traditional Strategies, Modern Decision-making and Management of Natural Resources in Forest and Pre-forest Zones of Africa." UNESCO - Management of Natural Resources in Africa: Traditional Strategies and Modern Decision-Making. MAB technical Note 9. Paris: UNESCO.

Savonnet, G. 1983. "Le refus paysan en Haute-Volta." Colloque International. Dévelopment Agricole et Parti cipation Paysanne, un Example: les Politiques de l'Eau, University of Paris 14-15 October, 1983.

Sawadogo, P. et al. 1975. Enquête socio-économique par entretien non-dirigé avec les exploitants dans parcelles de Tiebele. Ouagadougou.

SCET-Ministère de la Coopération Aménagement du delta Sénégal. 1969. Synthèse hydraulique du fonctionnement de l'axe Gorom-Lampsar. Paris: SCET/Ministère de la Coopération, 187 pp.

SCET-Ministère de la Coopération. 1964. Aménagement hydro-agricoles en Casamance et Haute-Gambie: Casamance con-tinentale. Etude hydrologique: Synthèse sommaire de deux années de mesures 1962 et 1963. Paris: CEE-SCET--Coopération, Mai, 64 pp.

SCET--Ministère de la Coopération. 1969. Aménagement hydro-agricole du delta du Sénégal. Cuvette de Boundoum ouest. Casier experimental. Puteaux: SEAE.

SCET--Ministère de la Coopération--SAEA. 1969. Aménagement hydro-agricole du delta du Sénégal. Vidange de la cuvette du Djoudj. Etude préliminaire. Paris: SCET--Ministère de la Coopération/SEAE, 28 pp.

SCET International. 1977. Manuel de gestion des périmètres irrigués. Collection, Techniques rurales en Afrique. Paris: Ministère de la Coopération, 272 pp.

SCET--AGRI. 1983. Inventaire des ressources en eau en vue d'aménagement hydrauliques à buts multiples en Guinée- Bissau. Etudes de factibilité et de projet, 5 Volumes. Paris: Ministère de la Coopération.

SCET--Ministère de la Coopération. 1970. Marais Rugezil et Kamiranzou Avant projet de mise en valeur hydro-agricole, 5 tomes. Paris: SCET/Ministère de la Coopération.

SCET--Ministère de la Coopération. 1962. Etude de réseau de collecte du nord-ouest du Lac Alaotra. Paris: SCET/ Ministère de la Coopération, Mars 1962, 6 pp.

SCET--COOPÉRATION--SEDES. 1963. Programme d'action régionale pour le département du sud-ouest. Les possi-bilities d'aménagement hydro-agricole de la basse vallée du Mono. Paris: Ministère de la Coopération.

SCET. Programme hydraulique au Sahel. 3 tomes. Paris: SCET-International.

Schliephake, K. 1972. "Die landliche Wasserversorgung in Nordafrika; Probleme und Zukunft de landwirtschaftlichen Bewasserung," Afrika Spectrum, 2, pp. 52-80.

Schmugge, T.J., Jackson, T.J. and McKim, H.L. 1981. "Survey of In-Site and Remote Sensing Methods for Soil Moisture Determination," pp. 333-352. In, Deutsch, Morris et al. (eds.) Satellite Hydrology. Minneapolis: American Water Resources Association.

Schoeller, H. 1959. Arid Zone Hydrology: Recent Develop ments. Paris: UNESCO.

Scholz, H. No date. Provisional map of South West Africa. (1:5,000,000). (Unpublished).

Schreyer, E. 1983. "Office du Niger: ein agro-industrielles Grossunternehmen ein Mali," Internationales Afrikaforum, 19,1, pp. 83-89.

Schulze, F. E. and N. A. D. E. Ridder. 1974. "The Rising Water Table in the West Nubarya Area of Egypt," Nature and Resources, Vol. 10, No. 1, pp. 12-17.

Schware, R. and Kellogg. 1982. "How Climatic Change Could Affect Food Production," Ceres 15(2), pp. 40-42.

Schwarz, Sabine. 1983. "Irrigation in Arid Areas--Its Limitations and its Rejection by Nomadic Pastoralists," pp. 191-211. DVWK Bulletin No. 8, Man and Technology in Irrigated Agriculture. Hamburg: Verlag Paul Parey.

Scobie, Grant M. 1981. Government Policy and Food Imports: The Case of Wheat in Egypt. (Research Report 29.) Washington, D.C.: International Food Policy Research Institute.

Scudder, Thayer. 1973. "Summary: Resettlement," Ackerman, White and Worthington (eds.). Man Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17. Washington, D. C.: American Geographical Union.

Scudder, Thayer. 1975. "Social Impacts of Integrated River Basin Development on Local Populations." Positional paper presented at UNDP/UN International Seminar on River Basin and Interbasin Development, 16-26 September. Budapest, Hungary.

Scudder, Thayer. 1980. "River Basin Development and Local Initiative in African Savannah Environments," Harris, B. R. (ed.), Human Ecology in Savanna Environments. London: Academic Press, pp. 383-406.

Scudder, Thayer. 1981. "From Relief to Development: Some Comments on Refugee and Other Settlement in Somalia." Unpublished paper, Institute for Development Anthropology, Binghampton, NY 41, pp.

Scudder, Thayer. 1985. "A Sociological Framework for the Analysis of New Land Settlements," pp. 121 153. In, Cernea, M. (ed.) Putting People First. New York: Oxford University Press.

SEAE. Exposé sur les problèms d'envasement. Paris: Maisons - Alfort, 48 pp.

Seck, S. M. 1981. Irrigation et aménagement de l'espace dans la moyenne vallée du Sénégal. Thèse pour le Doctorat d'Etat en Géographie, Université de St. Etienne.

SEDAGRI. 1968. Aménagement hydroagricole pilote dans la vallée l'Oueme. Programme Générale de travail. Paris: SEDAGRI, 69 pp.

Seddon, J. D. S. 1980. Changing Agriculture in the Sebra Plain, Northeast Morocco. Occasional Paper 7, School of Development Studies, University of East Anglia.

SEDES. 1960. Aménagements hydro-agricoles dans le bassin Solomougou: Etude Socio-Economique. Paris: SEDES, 84 pp.

SEDES. 1964. Barrage de Mbakaou: Etude préliminaire des possibilitiés d'utilisation du plan d'eau pour le dével-loppement rural. Paris: SEDES, 205 pp.

SEDES-SOGETHA-SOGREAH. 1967. Créations de périmètres irrigués expérimentaux dans la basse vallée du Mono. Paris/Grenoble: SOGREAH.

Sedwale, M. and L. Farr. 1980. Selected Groundwater Exploration Techniques: Karoo Areas - Results of their Application in the Serule Area, Botswana. Botswana: Department of Geological Survey.

Seguy, Lucien, Jacques Gigou, and Michael Raunet. 1976. "Un exemple de rélations, étude du milieu physique, expérimentation agronomique, mise en valeur: la culture du riz dans la plaine des M'Bos (Ouest Cameroun)," L'agronomie Tropicale, Vol. XXI, No. 2, Avril-Juin, pp. 114-140.

Sénégal, République du, Ministère de l'Economie Rurale et de la Coopération/Communauté Economique Européene, Fonds Européene de Développement. 1964. Aménagement hydro-agricoles en casamance et en Haute Gambie: Casamance Continentale etude hydrolique. Paris: GERCA, ILACEO, SCET.

Senegal, République du, Ministère de l'économie rural. 1965. Aménagement du delta du fleuve Sénégal. Villages enquête auprès du fonds AC. Dakar: Ministère de l'économie rurale.

Sénégal, République du, Ministère de l'économie rurale--Région du fleuve--SAED. 1965. Aménagement de la cuvette de Mboundoum nord. Trauvaux de l'aménagement périphique. Dossier de présentation au FAC. Dakar: Ministère de l'économie rurale/SAED.

Sénégal, République du, Ministère de l'économie rurale/SAED. 1966. Aménagement du delta Sénégal avant projet hydro-agricole. Rapport Générale, Décembre. Paris: SCET/Ministère de la Coopération, 42 pp.

Sénégal, République du. 1964. Aménagements hydro-agricoles en Casamance et Haute-Gambie: Casamance continentale. Etude hydrologique; synthèse sommaires des deux années de mesures, 3 Volumes. 1962-63. Paris: CEE/SCET/ Ministère de la Coopération, May 1964.

Sénégal, Republique du, SAED. 1975. Evaluation agro-économique des petits périmètres de Matam. St. Louis: Ministère de Développement Rurale et de l'Hydraulique, 26 pp.

Sénégal, République du. 1976. Programme d'action à court et Moyen termes: rapport de fin de premier phase. Dakar: Ministère du Développement Rurale et Hydraulique, SI, SAED, SCET, 6 Volumes.

Sénégal, République du, Ministère du Développement Rural et de l'Hydraulique. 1976. Projet de Formation du Personnel de la SAED et des Groupements des Groupements de Producteurs. Paris: SATEC, 1976.

Séné gal, République du. 1977. Loi-programme agricole: bilan diagnostique, analyse des systéme de production agricole et perspectives; étude analytique des different structures développement rural. Tome II. Dakar, Ministére du Développement Rural et Hydraulique, SAED, SONED, SEDES.

Sénégal, République du, Ministère du développement rurale/SAED. 1978. Dossier de consultation pour les études de factibilité et d'exécution de périmètre d'irrigation sur la rive gauche du fleuve Sénégal. Paris: Ministère de la Coopération/Bureau de Hydraulique, 75 pp.

Sénégal, République du, Ministère de développement rural. L'Eau et l'irrigation. Dakar: Ministère du développement rural, n.d., 24 pp.

Senghor, Adrien. 1978. Communication sur la politique de l'eau. Conseil National du 15 juillet 1978. Dakar: Ministere de l'equipement, 114 pp.

Serant, Yvon. 1975. "L'aménagement du fleuve Sénégal," Mer Outre Mer, Mars-Avril, pp. 11-13.

Shaheen, A. H. 1983. "Some Ecological and Biological Studies on the Potato Tuber Moth, Phthorimaea operculella Zell in Egypt," Bulletin de la Société Entomologique d'Egypt 1988/1979, published 1983, No. 62, pp. 135-145.

Shaner, W.W., Philipp, P.F. and Schmehl, W.R. 1982. Farming Systems Research and Development Guidelines for Developing Countries. Boulder, CO: Westview Press.

Shantz, Homer Leroy. 1923. The Vegetation and Soils of Africa. New York: National Research Council and the American Geographical Society.

Shaw, B. D. 1981. "Climate, Environment and History," Wigley, T. et al. (eds.), Climate and History Cambridge University Press, pp. 379-403.

Shaw, Margaret. 1979. Administrative Structures and Civil Service in the Sahel Countries. Washington, D.C.: Agency for International Development (Contract afr-c-1454, Aid Project 625-0920).

Shear, D. and B. Clark. 1976. "International Long-Term Planning for the Sahel." International Development Review, Vol. 4, pp. 15-20.

Shepherd, A. 1981. "Agrarian Change in Northern Ghana: Public Investment, Capitalist Farming and Famine," Heyer, J. et al. (eds.). Rural Development in Tropical Africa London, MacMillan, pp. 168-192.

Shepherd, A. W. 1980. "The Jamu'iya Scheme: Report on a Field Project," Occasional Paper No. 8. Development Administration Group, Institute of Local Government Studies, University of Birmingham, U. K. Farmers clash with government over development of riverain land.

Shepherd, Andrew. 1985. Water, Pastoralism and Irrigation Schemes in Eastern Sudan: Development of the Butana Prairie. Papers in the Administration of Development, No. 22. Birmingham: Birmingham University, 23 pp.

Siann, J. N. 1980. "Conflicting Interests in River Basin Planning: A Case Study." Unpublished paper presented at Seminar on River Basin Planning, Centre for Development Studies, University of Swansea, Wales.

Siann, J. M. 1981. "Conflicting Interests in River Basin Planning: A Nigerian Case Study," pp. 215-231. In, Saha, S. and Barrow, C. (eds.) River Basin Planning. Chichester, England: John Wiley.

Siann, J. M. 1982. "Labour Constraints in the Promotion of Irrigation Projects," Irrigation in Tropical Africa: Problems and Problem-Solving."

Silsoe College. 1985. "Small Scale Irrigation Schemes in Sub-Saharan Africa: Options Paper." Rome: DDC/FAO for International Fund for Agricultural Development, February, 46 pp.

Simeon, M. 1982. Etude de cas: Mali, Projet zone lacustre. Montpellier: Institut d'Agronomie Mediteranée, 17 pp.

Simmonds, Norman W. 1985. Farming Systems Research. A Review. World Bank Technical Paper No. 43. Washington, D.C.: The World Bank, 97 pp.

Simonet, Pierre. 1983. "Sénégal: Les besoins prioritaires," MOCI, No. 582, 21 Novembre 1983, pp. 81-82.

Simpson, G. 1976. "Socio-Political Aspects of Settlement Schemes in Ethiopia and Their Contribution to Development," Land Reform, Land Settlement and Co-operatives, No. 2, pp. 22-41.

Simpson, I. G. 1976. "The Sudan Gezira Scheme: Transformation and Evolution." Paper presented for the Conference: Accelerating National Agricultural and Rural Development. Reading, England: University of Reading.

Simson, I. G. 1976. The Sudan Gezira Scheme - Transformation and Evolution. International Seminar, University of Reading, Sept. 1976.

Singh, Shamsher. 1983. Sub-Saharan Agriculture. Synthesis and Trade Prospects. World Bank Staff Working Papers, No. 608. Washington, D.C.: The World Bank, 157 pp.

Singleton, C.B. 1974. A Case Study of the Effect of Organised Irrigation: The Mwea Irrigation Settlement, Kenya. 1973. Ph.D. Thesis, University of Edenburgh, 398 pp.

Sintas, Christine. 1980. Programme d'aménagement et d'assainissement des-puits dans l'arrondissement de Mayahi. Paris: Ministère de l'Hydraulique, Département de Maradi, 48 pp.

Sir M. MacDonald & Partners. 1978. Jowhar Sugar Estate-Drainage and Reclamation Study Drainage Trials, 1978. Somali Democratic Republic, Ministry of Industry.

Sircoulon, J. 1976. Données hydro-pluviométriques sur-la sécheresse de 1968 à 1963 en Centrafrique. Paris: ORSTOM, 22 pp.

Sisson, Andrew B. and Theodore Ahlers. 1981. The Socio-Economic Impact of SEMRI I: Economic Aspects. Research Report No. 1. Yaounde: CRED.

Siy, Robert Y., Jr. 1986. "Averting the Bureaucratization of a Community-Managed Resource--The Case of the Zanjeras," pp. 260-273. In, Korten, David (ed.) Community Management: Asian Experience and Perspectives. West Hartford, Conneticut: Kumarian Press.

Skogerboe, Gaylord V. et al. 1980. Development Process for Improving Irrigation Water Management on Farms. Executive Summary. Water Management Technical Report No. 65 A (AID/ta-C-1411). Fort Collins, Colo.: Water Management Research Project, Engineering Research Center, Colorado State University, 22 pp.

Small, Leslie. 1984. Irrigation and Human Welfare: A Workshop Report, (unpublished report). New Brunswick, N.J.: International Agricultural and Food Program, Cook College, Rutgers University.

Smil, Vaclav and Knowland, W.E. (eds.) 1980. Energy in the Developing World. New York: Oxford University Press.

Smith, G.K. 1962. Report on Soil and Agricultural Survey of Sene-Obosum River Basins (Ghana). Washington, D.C.: USAID (with map at 1:250,000).

Smith, Linda. 1983. Survey of Sixth Region Pump Farmers--1982-83 Wheat Campaign, (unpublished report). Bamako: USAID/Mali. 18 pp.

Smyth, A.J. and R.F. Montgomery. 1962 Soils and Land use in Central Western Nigeria. Lagos: Ministry of Agri- culture and Natural Resources.

Snyder, Francis G. 1981. Capitalism and Legal Change. An African Transformation. New York: Academic Press, 334 pp.

Snyder, Francis G. 1981 Irrigation and Human Welfare: A Workshop Report. New Brunswick, N.J.: International Agricultural and Food Program, Cook College, Rutgers University, 29 pp.

Society Nationale Pour le Developpement Rural. 1981. Bilan de Cinq Annes d'Activite de la SONADER. Mauritania: unpublished.

SOFRELEC. 1979. Aménagement du fleuve Niger dans son cours moyen. Etude de coordination des projects de Labezanga (Mali) et de Kandadji (Niger), 2 Volumes. Paris: SOFRELEC; Bamako: Ministere du Développement Industriel et du Tourisme; Niamey: Ministere des Travaux Publics des Transports et de l'Urbanisme.

SOFRELEC. 1980. Etude de factibilité du barrage de Kandadji. Note de synthèse générale. Paris: Compagnie Nationale du Rhone; Niamey: Haut Comissariat de l'Autorité du Barrage de Kandadji, 61 pp.

SOGETHA. 1963. Aménagement hydro-agricole de la vallée de goulbi de Maradi, avant projet, note de synthèse. Paris: SOGETHA.

SOGETHA. 1963. Aménagement, selon la méthode traditionelle, de)trois polders de la région des cuvettes du lac Tchad. Fort-Lamy: SOGETHA.

SOGETHA. 1963. Etude d'un polder expérimental dans la région de Bol. Fort Lamy: SOGETHA.

SOGETHA. 1965. Région de Ouagadougou. Cercles de Ziniare- Bousse-Ouagadougou-Sapone-Kombissiri. (with map at 1:200,000) Grenoble: SOGETHA.

SOGETHA. 1968. Les petits barrages en terre. Paris: SEAE, 241 pp.

SOGETHA. 1969. Etudes agro-économique sur les aménagements hydro-agricoles de la Maggia. Paris: SOGETHA. Pour le compte du Commissariat General au Développement. (République du Niger), mission 1966, 67, 68, 69. Rapport Final.

SOGETHA. 1969. Etude agro-économique de la vallée de Badeguicheri. Paris: SOGETHA. Pour le compte du Commissariat Général au Développement (République du Niger).

SOGETHA. 1969. Les ouvrages en Gabion. Techniques rurales en Afrique. Paris: Secrétariat d'Etat des affaires étrangers, 122 pp.

SOGETHA. 1969. *Les ouvrages d'un petit reseau d'irrigation. Techniques rurales en Afrique.* Paris: Ministère des relations extérieures, 192 pp.

SOGETHA. 1971. *Etudes agro-économique de l'aménagement hydro-agricoles d'Ibohamané.* Paris: SOGETHA. Pour le compte du Commissariat Général au Développement (République du Niger) Missions 1969, 70, 71. Rapport Final.

SOGETHA. 1974. *Les ouvrages d'un petit réseau d'irrigation.* Paris: SEAE, 192 pp.

SOGETHA. *L'utilisation agricole des eaux de crue en Afrique.* Grenoble: SOGETHA/Ouagadougou--CIEH, 3 Volumes.

SOGETHA. 1976. *Irrigation gravitaire par canaux; conception du périmètre, étude des canaux et leurs revêtements.* Paris: Ministère de la Coopération, 296 pp.

SOGREAH. *Aménagement de l'Aftout-es Sahel. Exécution des ouvrages d'infrastructure. Etude d'évaluation.* Paris: FAC; Nouakchott: Ministère d'Etat au Développement rural/SONADER, 65 pp.

SOGREAH. 1959. *Epandage d'eau de crue en pays Androy et Mahafaly: Rapport de mission, mai-juin 1959.* Tananarive: SOGREAH, 69 pp.

SOGREAH. *Programme de répartition de barrages en terre en Haute Volta. Rapport de expertise.* Paris: Ministère de la Coopération. Grenoble: SOGREAH, 39 pp.

SOGREAH. 1974. *Manuel de l'adjoint technique du génie rural. Traveaux sur un périmètre d;irrigation.* Paris: Ministère de la coopération, 380 pp.

SOGREAH. 1974. *Aménagement de l'Aftout es Sahel.* Paris: SOGREAH.

SOGREAH. 1976. *Irrigation gravitaire par canaux.* Conception de périmètre, étude des canaux et leurs revetements. Paris: Ministère de la coopération, 296 pp.

SOGREAH. 1978. *Les pompes et les petites stations de pompage. Collection Techniques rurales en Afrique.* Paris: Ministère de la Coopération, 217 pp.

SOGREAH. 1981. *Projet SEMRY II: Gestion hydraulique et entretien de l'aménagement.* Grenoble: SOGREAH, 66 pp.

SOGREAH. 1984. *Synthèse et Bilan des stations fournies par SOGREAH à l'office du Niger de 1978 a 1982. République du Mali, Afrique du Niger*, 63 pp.

Soil Conservation Service. 1975. Soil Taxonomy: A Basic System of Soil Classifcation for Making and Interpreting Soil Surveys. U.S. Department of Agriculture, Handbook No. 436.

Solages, S. 1979. Les captages d'eaux souterraines au Sénégal. Dakar: Ministère de l'équipement, 30 pp.

Solages, S. 1979. Utilisation des crepines à pointe pour l'exploitation d'aquifères sableux peu profonds. Possibilities d'application aux culture maraîcheres et à l'alimentation en eau potable sur les zones litorales au Senegal. Dakar: Ministère de l'équipement/Direction Générale de l'hydraulique, Urbaine et Rurale, 29 pp.

Soliman, M. M. et al. 1978. "Recent Technique for the Drainage Design in the Nile Delta." International Commission on Irrigation and Drainage. Tenth Congress on Irrigation and Drainage, Athens, 1978, Transactions Vol. IV. New Delhi, India:

Sombroek, W.G., H.M.H. Braun, and B.J.A. Van der Pouw. 1982. Exploratory Soil Map and Agro-Climatic Zone Map of Kenya, 1980, scale 1:1,000,000. Nairobi: Kenya Soil Survey.

Sonou, M. 1982. The Development of Small-Scale Irrigation in the Senegal River Basin.

Soper, R. 1981. "A Survey of the Irrigation systems of the Marakwet," pp. 75-95. B.E. Kipkorir et al. (eds.) Kerio Valley Past, Present and Future. (Proceedings of a Seminar Held in Nairobi, 21-22 May, 1981.) Nairobi: Institute of African Studies, University of Nairobi.

Sorbo, Gunnar, 1973. "Scheme and Off-Scheme Interests: A Study of Nubian Resettlement in the Sudan." Thesis, University of Bergen, Bergen, Norway.

Sorbo. Gunnar M. 1977. "Nomads on the Scheme: A Study of Irrigation Agriculture and Pastoralism in Eastern Sudan," O'Keefe, P. and Wisner, B. (eds.) Land Use and Development . African Environment Special Report No. 5. London: International African Institute.

Sorbo, Gunnar. 1985. Tenants and Nomads in Eastern Sudan. Uppsala: Scandinavian Institute of African Studies, 159 pp.

Sordiollet, R. 1965. Projet d'irrigation de Birni N'Konni. Paris; SATEL, 46 pp. Mimeo.

Soto, P.E. and Z. Siddiqi. 1978. "Insect Pests and Rice Production in Africa," pp. 175-180. In: Buddenhagen, I.W. and G.J. Persley, Rice in Africa. London: Academic Press.

Souhou, M. Notes on Guide-Lines for Small-Scale Irrigation in Africa. For presentation at a workshop on Irrigation in Tropical Africa, Cambridge, 1983.

Soumana, Seyni. Les problèmes d'approvisement en eau portable des zones rurales. Projet d'améloioration de la situation dans l'arrondissement de Tillabery au Niger. Rennes: Ecole Nationale de la Santé Publique/Section Para-Medicale, 1978-79, 56 pp.

Southwest Research Institute. 1982. A Technical Guide to Water Management on Small Farms. San Antonio, Texas: Southwest Research Institute for USAID, 91 p.

Sow, A. 1977. "Evolution du système de production agricole dans la région du Cap-Vert," Cahiers Africains d'Administration Publique, No. 17, Juillet, pp. 59-65.

Sow, Samba. 1965. Intégration de l'Elevage et des Eleveurs dans la Zone Pionnière du Delta. Dakar: College d'Aménagement du Territoire, Memoire de Stagiaire.

Sparling, Edward W. et al. 1980. Development Process for Improving Irrigation Water Management on Farms. Development of Solutions Manual. Water Management Technical Report No. 65 C. Fort Collins, Colo.: Colorado State University, 95 pp.

Sparling, Edward W. 1981. A Survey and Analysis of Ex-Post Cost-Benefit Studies of Sahelian Irrigation Projects. Fort Collins, Colo.: Colorado State University, Dept. of Economics

Spencer, Dunstan. 1981. "Rice Production in Sierra Leone." In: Pearson et al, Rice in West Africa. Stanford: Stanford University Press.

Spencer, Dunstan. 1981. "Sierra Leone," pp. 173-225. In, Pearson, Scott R., Stryker, J. Dirt, and Humphreys, Charles P. (eds.) Rice in West Africa. Stanford, California: Stanford University Press.

Sprague, G.F., ed. 1977. Corn and Corn Improvement. (Number 18 in the series Agronomy.) Madison, Wisconsin: American Society of Agronomy, Inc.

Ssenyonga, J. W. 1981. "The Marakwet Irrigation System as a Model of a Systems-Approach to Water Management." Paper presented for the Conference: Irrigation Development in Arid and Semi-Arid Areas of Kenya Limuru, Kenya.

Ssennyonga, J. W. 1983. "The Marakwet Irrigation System as a Model of a Systems-Apporach to Water Management," pp. 96-111. In, Kipkorir, B. E. et al. (eds.) Kerio Valley: Past, Present and Future. Nairobi: Institute of African Studies, University of Nairobi.

Ssennyonga, J. W. 1986. "Water User Organization," pp. 53-79. In, Coward, E. W. Jr. et al., Watering the Shamba. Ithaca, New York: Cornell University.

Stanley, N.F. and N.P. Alpers (eds.) 1975. Man-made Lakes and Human Health. New York: Academic Press.

Stann, J.M. 1983. "Labour Constraints in the Promotion of Irrigation Projects." Paper for the Workshop: Irrigation in Tropical Africa, Problems and Problem Solving. Cambridge, England: African Studies Centre, University of Cambridge, 10 pp. (mimeo).

Stanning, Jayne L. and Bloch, Peter C. 1986. "Zimbabwe: Sabi River Basin," pp. 96-115. In, Bloch, Peter, et al. Land Tenure Issues in River Basin Development of Sub-Saharan Africa. Madison, Wisconsin: Land Tenure Center, University of Wisconsin-Madison.

Steedman, C. et al. 1976. Mali: Agricultural Sector Assessment. Ann Arbor: Center for Research on Economic Development, Univ. of Michigan.

Steinberg, David I. et al. 1980. Philippine Small Scale Irrigation. Project Impact Evaluation No. 4. Washington, D.C.: U.S. Agency for International Development.

Steinberg, David I. et al. 1983. Irrigation and Aid's Experience: A Consideration Based on Evaluations. A.I.D. Program Evaluation Report No. 8. Washington, D.C.: U.S. Agency for International Development, 237 pp.

Stelly, M. (ed.) 1978. Diversity of Soils in the Tropics. American Society of Agronomy, Special Publication No. 34.

Stengel, H. W. 1964. The Rivers of the Namib and Their Discharge into the Atlantic Part I: Kuiseb and Swakop. Namib Desert Research Station Scientific Paper 22. South Africa.

Stephens, C. (ed). 1984. "Renegotiating Lome." EEC and the Third World: A Survey, Part 4. London: Overseas Development Institute.

Stern, P.H. 1979. Small-Scale Irrigation. London: Intermediate Technology Ltd./Bet Dagan, Israel: International Irrigation Information Center.

Stern, Peter H. 1981. Report on the Approach to Small-Scale Irrigation in Kano State, Nigeria. Southampton, England: P. Stern for FAO/World Bank Cooperative Programme.

Stern, Peter H. 1983. "Low Cost Pumps for the Third World," Paper 20 for the Eighth Technical Conference, Pumps-the Heart of the Matter, British Pump Manufacturers' Association (29-31 March, 1983, Cambridge), pp. 260-270.

Stock, Robert F. 1977. "The Impact of the Decline of the Hadejia River Floods in Hadejia Emirate," Van Apeldoorn, G. Jan (ed.), The Aftermath of the 1972-74 Drought in Nigeria, pp. 141-146 Proceedings of a Conference held at Baganda. Zaria, Nigeria: Federal Department of Water Resources and the Centre for Social and Economic Research, Ahmadu Bello University.

Stocking, M. 1983. "Extremely Rapid Soil Survey: An Evalu- ation from Tanzania." Soil Survey and Land Evaluation, 3(2):31-36.

Storer, J. R. 1976. "Irrigation Helps Former Pastoralists in Arid Kenya. FAO/FFHC Turkana Irrigation Project, Lodwar, Kenya," World Crops, 28, 2, pp. 56-58, 60.

Storm, R. 1976. "Government Cooperative Groundnut Marketing in Senegal and Gambia." Journal of Rural Cooperation, Vol. 5, no. 1, pp.

Stow, D. A. V., J. Skidmore, and A. R. Berger. 1976. Preliminary bibliography on groundwater in developing countries 1970-1976. The Geosciences in International Development Report No. 14. Canada: Association of Geoscientists for International Development Report No. 4. (Dept. of Geology, Memorial University, St. John's, Newfoundland, Canada AIC 557).

Striffler, William and Fitz, Diana C. 1980. Applications of Remote Sensing in Hydrology. Colorado Water Resources Research Institute Completion Report No. 99. Fort Collins, Colorado: Colorado Water Resources Research Institute, Colorado State University, 41 pp. and appendices.

Stryker, Dirck J. 1976. "Population Density, Agricultural Technique, and Land Utilization in a Village Economy," American Economic Review, Vol. 66, pp. 347-358.

Stryker, Dirck J. 1978. Food Security, Self-Sufficiency, and Economic Growth in the Sahelian Countries of West Africa. Palo Alto, Calif.: Food Research Institute, Stanford University.

Stryker, Dirck J. 1978. "Rainfed Farming and Irrigation Options in West Africa." Joyce, Charles (ed.) Towards a Rational U.S. Policy on River Basin Development in the Sahel. Washington, D.C.: Agency for International Development.

Stryker, Dirck J. 1981. "Comparative Advantage and Public Policy in West African Rice," pp. 396-431. In: Pearson, Scott R., J. Dirck Stryker, Charles P. Humphreys, et al, Rice in West Africa. Stanford, California: Stanford University Press.

Stryker, Dirck J., et al. 1981. Investments in Large Scale Infrastructure: Irrigation and River Management in the Sahel. (Final Report, revised version.) Stanford, California: Stanford University and Tufts University.

Stryker, Dirck J. and C. H. Gotsch. 1982. "Investments in Large-Scale Infrastructure: Irrigation and River Management in the Sahel." AID Research and Development Abstracts 1982, 10, 3/4, pp. 34-35.

Stryker, Dirck J., John M. Page, Jr., and Charles P. Humphreys. 1981. "Appendix B - Shadow Price Estimation," pp. 455-482. In: Pearson, Scott R., J. Dirck Stryker, Charles P. Humphreys, et al, Rice in West Africa. Stanford, California: Stanford University Press.

Sudan Plantations Syndicat. 1951. A Hand Book for New Personnel. Sudan Gezira Board.

Sutcliffe, J. V. 1976. "Hydrological Study of the Southern Sudd Region of the Upper Nile," Proceedings of the Symposium on the Okovango Delta and its Future Utilisation.

Swaminathan, M.S. 1984. Scientific American, vol. 250, no. 1 (January), pp. 80-93.

Swan, C. H. 1983. "Relations between Management, Government and Tenants with Respect to Irrigation Water in Gezira, Sudan." Paper presented for the International Conference: Développement agricole et participation paysanne, une exemple: les politiques de l'eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Swynnerton, R. 1982. Irrigation Project Management and Its Implications for Design and Irrigation Schemes. ICID Bulletin, Vol. 31, No. 2, 1982, pp. 25-33, 38.

Sys, C. 1960. Carte (1:5,00,000) des sols et de la Vegetation du Congo belge et du Ruanda-Urundi. Bruxelles: INEAC.

Taha, T. E. J. 1975. "The Development of the Managil South-Western Extension of the Gezira Scheme, Sudan." Land Reform (FAO), no. 1, pp. 25-37.

Tait, John. 1983. "The Modernization of the Colonial Mode of Production in the Gezira Scheme," pp. 81-135. In, P. Oesterdiekhoff and K. Wohlmuth (eds.), The Development Perspectives of the Democratic Republic of the Sudan: The Limits of the Breadbasket Strategy. IFO Institut Afrika Studien, Nr. 109. Munich: Weltforum Verlag.

Tanzania Department of Lands and Surveys. 1956. "Soil map of Tankanyika at 1:3,000,000." Atlas of Tanganyika. Dar es Salaam.

Tawadros, H. W. 1982. "Influence of Irrigation on Faba Beans in Egypt. Soil and Water Research Institute, Agricultural Research Centre, Giza, Cairo, Egypt," FABIS Newsletter 1982, No. 5. 16 pp.

Taylor, G. C. 1971. Techniques for Assessing Water Resource Potentials in the Developing Countries. Washington: United States Geological Survey.

Tchad, République du, Société de développement du lac (SODELAC). 1972. Aménagement des polders de Bol Etude de factibilité, 7 Volumes. Paris: SCET.

Tchad, République du. Assessment du polder du Mamdi Projet d'appel d'offre de fourniture, 4 Volumes. Ndjemena: SODELAC; Puteaux: SCET.

Tchad, République du. 1966. Etude d'un polder expérimental dans la région de Bol. (Etudes préliminaires et avant projets), January. Ndjamena: Service de génie rural et de l'hydraulique agricole/SOGETHA.

Tchad, République de. Etude préliminaire de la protection des berges du Chari. Paris: BCEOM.

Tchad, République du, Bureau de l'eau. 1974. Inventaire bibliographique du Bureau de l'eau à la date du 1er janvier 1975. Classement par régions. Ndjamena: Bureau de l'eau.

Tchala-Abina, F. 1982. The State, the Bureaucracy, and Farmers in Rural Development: A Case Study of the Social Relations of Production in Selected Development Corporations in Cameroon. Ph.D. Thesis, Cornell University, 456 pp.

Telford, A. 1950. Report on the Agricultural Development of the Limpasa Dambo, Nyasaland. London: Colonial Development Corporation.

Temerak, S. A. 1983. "Field Management of the Potato Tubeworm. Phthorimaea operculella (Zeller), Infesting Certain Potato Varieties through Manipulation of Different Levels of Irrigation," Bulletin de la Société Entomologique d'Egypte 1978/79. Published 1983, No. 62, pp. 153-160.

Temple Hazell, J. R. Water Surveys (Nigeria) Ltd. 1984. Distribution, Availability and Use of Groundwater for Irrigation in the Northern Zone, Bauchi State ADP. Photocopy of report received from ODI.

Ter-Minassian, Waik. 1977. "Le barrage sur mesure." "Actual Developpment." No. 21, Nov.-Dec. 1977, pp. 40-51.

Tettey, E.A. 1982. A Decision Analysis for a Comprehensive Operational Sahelian Model of Opportunity (COSMO). An Educational Policy Model for Developing Human Resources in the Sahel Regions. Ph.D. Thesis, Florida State University, 204 pp.

Theisen, A. A., E. G. Knox, and F. L. Mann. 1978. Feasibility of Introducing Food Crops Better Adapted to Environmental Stress, Volume I. Soil and Land Use Technology, Inc.

Theisen, A. A., E. G. Knox, F. L. Mann, and H. B. Sprague, 1978. Feasibility of Introducing Food Crops Better Adapted to Environmental Stress. Volume II, Individual Crop Reports. Soil and Land Use Technology, Inc.

Thevenin, Pierre. 1982. Synthèse des évaluations riz-coton arachides au Sénégal. Paris: Ministère des Relations Extérieures Coopération et Développement, 47 pp.

Thom, D.J., D.C. Slack, M.B. Lynham. 1985. Pre-Feasibility Study of Irrigation Development in Mauritania. Water Management Synthesis, Report 51, Logan, Utah: Utah State University.

Thom, Derrick J. and John C. Wells. 1987. "Farming Systems in the Inland Delta, Mali," Geographical Review, Vol. 77, #3, July 1987, pp. 328-342.

Thomas, M. F. and Whittington, G. W. (eds.) Environment and Land Use in Africa. London: Methuen.

Thomas, M. F. 1969. "Geomorphology and Land Classification in Tropical Africa," pp. 103-145. In, Thomas, M. F. and Whittington, G. W. (eds.) Environment and Land Use in Africa. London: Methuen.

Thompson, B. W. 1965. The Climate of Africa. Nairobi: Oxford University Press."

Thompson, J.G. 1965. The Soils of Rhodesia and Their Classification and Explanatory Soil Map of Rhodesia at Approximately 1:1,000,000. Harare: Government Printer.

Thompson, K. and A.C. Hamilton. 1983. "Peatlands and Swamps of the African Continent." pp. 331-373. A.J.P. Gore (ed.). Mires: Swamp, Bog, Fen and Moor. Regional Studies. Volume 4B. Elsevier Scientific Publishing Company, Amsterdam, Netherlands.

Thornton, D. S. 1972. "Agricultural Development in the Sudan Gezira Scheme," Tropical Agriculture, (Trinidad) Vol. 49, No. 2, April. University of the West Indies.

Thornton, D. S., and R. F. Wynn. 1968. "An Economic Assessment of the Sudan's Khasm el Girba Scheme," East African Journal of Rural Development, Vol. 1, No. 2, July.

Thornthwaite, C. W. 1962. Average Climatic Water Balance Data of the Continents, Part 1 Africa. Laboratory of Climatology, Centreton, New Jersey: C. W. Thornthwaite and Associates.

Tiffen, Mary. 1976. The Enterprising Peasant. London: HMSO.

Tiffen, Mary. 1983. "Peasant Participation in District Water Planning. An Example from Machakos District, Kenya." Paper presented for the International Conference: Développement Agricole et Participation Paysanne. Un Exemple: Les Politiques de L'Eau en Afrique. University of Paris I, Centre d'Etudes Juridiques Comparatives.

Tiffen, Mary. 1983. Alternative Design Concepts for Irrigation Systems. Irrigation Management Network Paper 8e. London: Overseas Development Institute.

Tiffen, Mary. 1984. "Human Resources in African Irrigation," pp. 57-73. In, Blackie, M.J. (ed.) African Regional Symposium on Small Holder Irrigation. Wallingford, England: Hydraulics Research for University of Zimbabwe, Harare.

Tiffen, Mary. 1984. "Notes on Vegetable Marketing and Processing, and Land Tenure in Azare and Adjacent Areas," Report for the second Fadama Seminar, Azare, 6-8 March (Chapman, N. P. (ed.)). Bauchi State Agricultural Development Programme, Northern Zone, Nigeria.

Tiffen, Mary. 1985. "Improving the Socio-Economic and Institutional Context of Irrigation Feasibility Studies," London: Overseas Development Institute.

Tiffen, Mary. 1985. "Peasant Participation in District Water Planning. An Example from Machakos District, Kenya," pp. 3563-375. In, G. Conac, et al. (eds.) Les Politiques de L'eau en Afrique: Développement agricole et participation paysanne. Paris: Economica.

Tiffen, Mary. 1986. "The Identification of Crucial Socio-Economic and Institutional Parameters for the Design of Irrigation Systems," pp. 327-241. In, Hydraulics Research, Irrigation Design for Management, Asian Regional Symposium (16-18 February 1987). Wallingford, England: Hydraulics Research.

Tiharuhondi, E. R. et al. 1973. "Application of nitrogen and irrigation to pasture to enhance cattle production during the dry seasons in Uganda," East African Agricultural and Forestry Journal, 38, 4, pp. 383-393.

Tillman, Gus. 1981. Environmentally Sound Small-Scale Water Projects Guidelines for Planning. New York: CODEL/ VITA, 142 pp.

Tobias, C. 1976 Utilisation du sol et possibilitiés d'irrigation dans la région de N'Djamena. ORSTOM: Notes Techniques du Centre ORSTOM de N'Djamena, No. 13, 14 pp.

Toksoz, Sadik. 1981. An Accelerated Irrigation and Land Reclamation Programme for Kenya. Development Discussion Paper No. 114, Harvard Institute for International Development, U.S.A.

Toulmin, C. 1983. Economic Behaviour among Livestock - Keeping Peoples: a Review of the Literature on the Economics of Pastoral Production in the Semi-arid Zones of Africa." Occasional Paper 25, School of Development Studies, University of East Anglia, UK.

Touré, M. and G. Arial. 1978. "Chemistry of Flooded Soil in Marine Alluvium of the Casamance, Senegal, and Its Relation to Rice Growth," pp. 257-269. In: Buddenhagen, I. W. and G. L. Persley, Rice in Africa. London: Academic Press.

Touré, Oumara. 1976. L'aménagement du Niger: le cas des aménagements hydro-agricoles du Tillaberi. Paris: Ecole des Hautes Etudes en Sciences Sociales, 169 pp.

Traoré, B. 1980. "Socioeconomic Field Assessment of Prospective Technologies in the SAT of Mali: A Case Study in an OACV Zone," pp. 125-146. ICRISAT, Proceedings of the International Workshop on Socio-economic Constraints to Development of Semi-Arid Tropical Agriculture. Patancheru, India: ICRISAT.

Traverse, S. 1975. "Traditions et Modernisation des Techniques de Riziculture en Basse-Casamance (Senegal)," Agronomie Tropicale, Vol. 30, No. 1, pp. 28-34.

Tricart, J. 1960. "A Geomorphological Study of the Scheme for the Development of Lake Faguibine (Mali Republic)," African Soils Vol. V, No. 3, pp. 207-289.

Tricart, Jean. 1962. L'aménagement du lac Faguibine (République du Mali). Paris: Presse Universitaire Française, 40 pp.

Trilsbach, A. 1986. "Agriculture West of the White Nile," pp. 46-64. In., Davies, H.R.J. (ed.) Rural Development in White Nile Province, Sudan. Tokyo: United Nations University.

Trouve-Bessat, Collete. 1981. "Sahel: L'irrigation, oui: mais pour qui?" Croissances des Jeunes nations." No. 226, Mars 1981, pp. 27-29.

Tucker, C.J., J.R.G. Townshend and T.E. Goff. 1985. "Africa Land-Cover Classification Using Satellite Data". Science, 227(4685):369-375.

Tuckett, J. R. 1977. "Vuvulane Irrigation Farms, Swaziland: a Report on the First Ten Years," Agricultural Administration, Vol. 4, No. 2.

Tuluy, A. Hasan. 1981. "Rice Production in Senegal." In: Pearson et al, Rice in West Africa. Stanford: Stanford University Press.

Tuluy, H.A. 1980. River Basin Development Alternatives: The Economics of Small-Scale Irrigation along the Senegal River. Ph.D. Thesis, Fletcher School of Law and Diplomacy, Tufts University.

Turlin, H. L. 1967. Opération régionale du pays Dogon. Bamako: Institut d'économie rurale. 3 Volumes.

Turner, B. 1977. The Fadama Lands of Central Northern Nigeria. Ph. D. Thesis, University of London.

Turner, Beryl. 1986. "The Importance of Dambos in African Agriculture," Land Use Policy, vol. 3, no. 4, pp. 343-347.

Turner, S. 1980. The Gezira Scheme. Restructuring the Future, Sudanow, Vol. 5, No. 3, 1980, pp. 33-46, 13 fig, 1 map.

Uganda Department of Agriculture. 1961. East Africa Soil Map at 1:250,000. (Sheets for Fort Portal, Hoima, Gulu, Kaabond, Kabale, Arua, Aloi, Kapenguria, Pakwach, Morotro, Mbarara, Masaka, Kitgum, Kampala). Entebe: Uganda Department of Agriculture.

Uganda Department of Lands and Surveys. 1962. "Soil map at 1:1,500,000." Atlas of Uganda. Entebbe.

Umbadda, S. and Abndul Jalil, M. A. 1985. "Women in Small-Scale Irrigated Agriculture: the Case of Wadi Kutum (Sudan)," Afrika Spectrum, vol. 20, no. 3. pp. 339-351.

Underhill, H.W. 1984. Small-Scale Irrigation in Africa - In the Context of Rural Development, Land and Water Development Division, FAO, Rome 1984.

UNDP. 1968. Uganda: Karamoja Groundwater Survey. Final agency statement. New York: UNDP.

UNESCO. 1969. List of International Hydrological Decade Stations of the World. UNESCO, Studies and Reports in Hydrology 6. Paris: UNESCO.

UNESCO. 1970. Hydrology of Deltas, Vol. 1 and 2. UNESCO Studies and Reports in Hydrology 9. Paris: UNESCO.

UNESCO. 1973. Design of Water Resource Projects with Inadequate Data, Vols. 1 & 2, UNESCO Studies and Reports in Hydrology 16. Paris: UNESCO.

UNESCO. 1974. Discharge of Selected Rivers of the World. Volume 1 - General and regime characteristics. Volume 2 - Monthly and annual discharges (start of record - 1964). Volume 3 - Mean monthly and extreme discharges (1969-1972) UNESCO Studies and Reports in Hydrology 5. Paris: UNESCO.

UNESCO. 1975. Hydrology of Marsh-Ridden Areas. UNESCO Studies and Reports in Hydrology 19. Paris: UNESCO.

UNESCO. 1978. Regional Meeting on Integrated Ecological Reasearch and Training Needs in North East Africa and in the Near and Middle East, with Emphasis on the Ecological Effects of Irrigation Derived from Large River Basins. Alexandria, 24-27 February 1976. Final report, MAB Report Series, UNESCO, No. 40, 1978, 77 pp.

UNESCO. 1978. World Water Balance and Water Resources of the Earth. Paris: UNESCO, 663 pp.

UNESCO. 1979. Centre régional d'energie solaire pour les pays de la communauté de l'Afrique de l'Ouest. Paris: Communauté Economique de l'Afrique de l'Ouest, 190 pp.

UNESCO. 1980. Surface and -Groundwater Interaction. UNESCO Studies and Reports in Hydrology 29. Paris: UNESCO.

United Nations. 1960. Large Scale Groundwater Development. New York: United Nations.

United Nations. 1966. Hydrological Survey (Limpopo River Basin and Okovango Delta). Botswana: Ministry of Commerce, Industry and Water Affairs.

United Nations. 1973. Groundwater in Africa. New York: United Nations.

United Nations. 1975. Management of Internal Water Resources: Institional and Legal Aspects. Natural Resources/Water Series No. I. New York: Dept. of Economic and Social Affairs, United Nations (E.75.II.A.2), 271 pp.

United Nations. 1977. Economic Commission for Africa - Regional Report. UN Water Conference, Mar del Plata, Argentina, 14-25 March 1977. New York: United Nations.

United Nations. 1977. Irrigation Management in Developing Countries : A suggested Action Programme. U.N. Water Conference Mar del Plata, Argentina, 14 - 25 March 1977. Pap. n TP219, pp. 1-3.

United Nations. 1977. Water Resources, Planning and Management: A Select Bibliography. New York: United Nations (Dag Hammarskjold Library), 117 pp.; overall biblio. organized geographically and topically.

United Nations Development Programme. 1980. Development of the Gambia River Basin. Multidisciplinary Multidonor Mission. Final Mission Report, Chapters I-IV. New York: UNDP.

United Nations. 1983. Experiences in the Development and Management of International River and Lake Basins. Natural Resources/Water Series, No. 10. New York: Dept. of Technical Co-operation for Development, United Nations (ST/ESA/120), 424 pp.

United Nations Institute for Training and Research. 1982. Alternative Strategies for Desert and Management, vol. 3: Water. New York: Pergamon Press.

University of Gezira. 1979. Aquatic Weed Management: Integrated Control Techniques for the Gezira Irrigation Scheme. Wad Medani, Sudan: University of Gezira jointly with National Academy of Sciences, USA.

University of Purdue. 1978. The Costs-Benefits From Small and Medium-Sized Perimeters in the Sahelian Countries. West Layafette: Dept. of Agricultural Economics, West Africa Program; ICRISAT, 103 pp.

Uphoff, Norman. 1985. "Fitting Projects to People," pp. 359-395. In, Cernea, M. (ed.) Putting People First. New York: Oxford University Press.

Uphoff, Norman T., John M. Cohen and Arthur Goldsmith. 1979. Feasibility and Application of Rural Development Participation: A State-of-the-Art Paper. Ithaca, N.Y.: Center for International Affairs, Cornell University, 338 pp.

Upton, M. 1969. Irrigation in Botswana. Development Study No. 5. Department of Agricultural Economics, University of Reading, England.

USAID. 1975. Development Assistance Program: Central West Africa Region, Annex E: Niger. Washington, D.C.: USAID.

USAID. 1975. Health in Africa. Washington, D.C.: Office of Development Services, Bureau for Africa, USAID, 91 pp.

USAID. 1976. Proposals for a Long-Term Comprehensive Development Program for the Sahel. Part II. Technical Background Papers. Washington, D.C.: Aid, 239 pp; see esp. "Water Resources," pp. 173-212.

USAID. 1976. Report to the United States Congress: Proposals for a Long-Term Comprehensive Development Program for the Sahel. Part II. Technical Background Papers. Washington, D.C.: AID.

USAID. 1979a. Evaluation of the Rice Production Accelerated Impact Project, Guinea-Bissau.

USAID. 1979b. Project Seneriz: Hydro-Agro Development of the Anambe Basin. Dakar, Senegal: USAID.

USAID. 1981. Action Riz-Sorgho Project Evaluation. Bamako: U. S. Agency for International Development.

USAID. 1982. U.S. Development Objectives in the Senegal River Basin. Dakar: River Basin Development Office, USAID/Senegal, 50 pp.

USAID. 1982. Project Identification Document, Agricultural Sector Grant. Niamey, Niger: U. S. Agency for International Development.

USAID, River Basin Development Office. 1983. Integrated Development Project, 3 vols. Dakar, Senegal: U. S. Agency for International Development.

USAID. 1984. Niger Irrigation Subsector Assessment. Niamey: USAID (May).

USDA. 1978. Plant Responses to Salinity: an indexed bibliography. Berkeley, California: USDA.

USDA. 1980. Food Problems and Prospects in Sub-Saharan Africa. The Decade of the 1980s. Washington, D.C.: International Economics Division, USDA for USAID, 414 pp.

USDA/USAID. 1968. Rice in West Africa. Washington, D. C.: USAID.

USDA/USAID. 1973. Techniques for Assessing Hydrological Potentials in Developing Countries (State of the Art and Research Priorities). Washington: Office of Science and Technology, AID.

USDA/USAID. 1980. The Impact of Irrigation on Development: Issues for a Comparative Evaluation Study. Washington, D. C.: AID Evaluation Discussion Paper, No. 9; Office of Evaluation, Bureau for Program and Policy Coordination AID, Oct. 1980, 70 pp.

Ushe-Uba. 1973. An Analysis of the Spatial Patterns and Physical Determinants of Agricultural Systems in the Hadejia floodplain. M. A. Thesis, Amadou Bello University, Nigeria.

Vachette, Philippe. 1973. Les transformations socio-économiques résultant d'un aménagement hydro-agricole dans un paysannat traditionnel: l'example d'Ibohamané au Niger. Paris: IEDES, 173 pp.

Vaillant, Louss Ouarn. 1970. Le choix des materiaux pour les conduits d'adduction et de distribution d'eau. Paris: SEAE., 384 pp.

Vainio-Mattila, Arja. 1985. "Socio-Economic Studies on Fuelwood Production in the Bura Settlement Scheme in Eastern Kenya," pp. 128-137. In, Hjort, Anders (ed.) Land Management and Survival. Uppsala: Scandinavian Institute of African Studies.

Vainio-Mattila, Arja. 1987. Bura Fuelwood Project: Domestic Fuel Economy. Report 13/1987 B. Helsinki: Institute of Development Studies, University of Helsinki, 164 pp.

Valet, S. 1977. Détermination in situ des proprietés physiques, hydriques et hydrodynamiques des sols des terrasses du Niger. Niamey: INRAN, 10 pp.

Valet, S. 1977. Rapport sur la second prospection hydro-pédologiques des sols des terrasses du Niger à Sona; mise au point d'une méthologie simple; étude de la variabilité des résultats des facteurs hydriques. Niamey: INRAN/GERDAT.

Valet, S. 1979. Résultats d'essais d'irrigation de complément sur sorgho-arachide et Coton sur le périmètre irrigué de Losa-saison des pluies '79. Niamey: INRAN, 53 pp.

Valet, S. and J. Marcesse. 1980. "Prospection hydropédologique, amélioration foncière et essais d'irrigation sous cultures, en vue de l'aménagement des terasses de recherche à l'aide de sondes à neutrons)," Agronomie Tropicale, Vol. 35, No. 2, pp. 115-134.

Vallée, G. 1980. "Utilisation des techniques culturales dans la lutte contre le riz sauvage annuel (O. Barthii) dans le Boucle du Niger (Mali)," Agronomie Tropicale, Vol. 35, No. 1, pp. 54-57.

van Amelsvoort, V. 1971. "Rural Water Supply Development and the Recent Appearance of Endemic Goitre," Tropical and Geographical Medicine, 23, pp. 304-305.

van Apeldoorn, G. J. 1981. Perspectives on Drought and Famine in Nigeria. London: George Allen and Unwin.

Van Breeman, N. 1980. "Acidity of wetland soils, including Histosols, as a constraint to food production," pp. 189-202. In: International Rice Research Institute, Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics. Manila: International Rice Research Institute.

Vandenput, Rene. 1981. Les principales cultures en Afrique Centrale. Bruxelles: l'Administration Générale de la Coopération au Développement, 1252 pp.

van der Leeden, F. (ed). 1975. Water Resources of the World: Selected Statistics. Section 2 Africa. Washington: Water Information Centre.

van Dijken, H. 1972. "Het Habra-project in Algerije--een drainage--en zoutstudie in een inrrigatie project." Landbouwkundig Tijdschrift, 84, 11, pp. 408-416.

van Parys, A. 1959. "Les cultures en marais draines en Ituri," Bulletin d'Information de l'INEAC, Vol. 8, pp. 375-390.

van Stratan, J. 1954. "The Geology and Groundwaters of the Ghanzi Cattle Route," Geological Survey of the Bechuanaland Protectorate Annual Report, pp. 31-33.

van Tuu. 1982. Mission d'inventaire et d'évaluation dans le Haut-Bassin du fleuve Gambie. Dakar: OMVG, Ministères des Rélations, Extérieures Coopération et de Développement, 83 pp.

van Wambeke, A. 1963. Carte des sols et de la vegetation du Congo, du Ruanda et du Burundi au 1:1,000,000. Burcelles: INEAC.

van Wambeke, A. 1982. Calculated Soil Moisture and Temperature Regimes of Africa. United States Department of Agriculture, Soil Conservation Service, Soil Management Support Services Technical Monograph 3. Berkeley, California: USDA.

Vercambe, B. 1982. "Diopsis thoracica West (Dipt. Diopsidae), important ravageur du riz en Afrique de l'Ouest: Données Bio-écologiques et Application à la lutte integree," Agronomie Tropicale, Vol. 37, No. 1, pp. 89-98.

Verlet, M. 1963. Aspects humains de l'utilisation de trois polders de la région du lac (Soro Dalairom, No. Madirom et Tchingam). Paris: BDPA, 172 pp.

Viguier, P. 1945. "Les sorghos à grain et leur culture au Soudan Français," Revue de Botanique Appliquée et d'Agriculture Tropicale, Vol. 25, pp. 163-225.

Vincent, L. 1978. A Summary of the Water Resources Available for the Development of Village Water Supplies throughout Kano State, Nigeria. World Bank/Overseas Development Group, University of East Anglia, UK.

Vincent, L. 1980. Efficiency as a Concept in Irrigation Design. School of Development Studies, Discussion Paper 68, University of East Anglia, UK.

Vincent, L. 1980. Irrigated Farming: Debt or Profit? Underutilisation of Water in the Medjerda Scheme, Tunisia. School of Development Studies, Discussion Paper 69, University of East Anglia, UK.

Vincent, L. 1981. Planning without People: the Chiwefwe Mixed Farming Project, Mkushi District. Agriplan Training Project: Case studies. Overseas Development Group: University of East Anglia, UK, and FAO: Rome.

Vincent, L. 1981. Irrigated Vegetable and Fruit Production in Mumbwa District. Agriplan Training Project: Case Studies. Overseas Development Group, University of East Anglia, UK and FAO: Rome.

Vincent, L. 1984. Prospects for Irrigation Development in Hydrological Environments of Africa. A Literature Review and Annotated Bibliography. (Background Paper for African Irrigation Overview.) Norwich, England: Overseas Development Group, University of East Anglia. 150 pp.

Vincent, L. and M. Elling. 1981. "The Natural Resources of Central Province," FAO/Overseas Development Group, Background to Agricultural Development in Central Province, Zambia. Rome: FAO, pp. 119-144. Overseas Development Group, University of East Anglia, UK.

Vink, N. 1983. Small-Scale Irrigation in Africa. Country Notes: Upper Volta, Niger, Mali. Rome: Land and Water Development Division, FAO.

Virmani, S. S., J. O. Olufowote, and A. O. Abifarin. 1978. "Rice Improvement in Tropical Anglophone Africa," pp.-. In: Buddenhagen and Persley, Rice in Africa. New York: Academic Press.

Vlachos, Evan. 1972. "Socio-Economic Aspects of Irrigated Agriculture." Paper for Seminar on Prospects for Irrigation in West Africa, held at Ibadan, Nigeria (Oct. 23-27, 1972). Ibadan, 113 pp. (Jointly sponsored by Ford Foundation, L'Institut de Recherches Agronomiques Tropicales et des Cultures Vivriès, and IITA.)

Vogel, Jean. 1983. "Heurs et malheurs de l'aménagement des vallées des Voltas," Croissance des Jeunes Nations, No. 247, fevrier, pp. 27-30.

Volkoff, B. and P. Willaime. 1963. Carte des sols du Dahomey au 1:1,000,000. Cotonou: ORSTOM.

Wagner, E.G. and J.N. Lanoix. 1959. Water Supply for Rural Areas and Small Communities. Geneva: WHO.

Waldstein, Abraham S. 1978. Government Sponsored Intensificaton Schemes in the Sahel: Development for Whom? Abidjan: REDSO/USAID, 114 pp.

Walker, Hans H. 1984. "Problems of the Organization of Irrigation Projects. A Systems-Oriented Study of Irrigation Projects in Developing Countries." pp. 20-45, Applied Geography and Development. Tübingen: Institute for Scientific Co-operation.

Walker, H. H., Castell, Wolfgang Graf zu. 1979. "The Contribution of Organisation Analysis to the Appraisal of Development Projects--the Example of the Ahero Pilot Irrigation Scheme in Kenya," Zeitschrift fur Auslandische Landwortschaft, Vol. 18, No. 1, pp. 49-68.

Wallace, I. 1979. Planning for Agricultural Development: A Consideration of Some of the Theoretical and Practical Issues Involved. Department of Research and Consultancy, Ahmadu Bello University, Zaria, Nigeria, 24 pp., 53 ref, BIDS.

Wallace, T. 1980. "Agricultural Projects and Land in Northern Nigeria," Review of African Political Economy, No. 17, Jan-April, pp. 59-70.

Wallace, T. 1981. "The Kano River Project, Nigeria: The Impact of an Irrigation Scheme on Productivity and Welfare," Heyer, J. et al (eds.). Rural Development in Tropical Africa. London: MacMillan, pp. 201-306.

Wallace, T. 1982. "Irrigation Schemes in Northern Nigeria and the Dream of Agricultural Plenty" (abstract). Book of Abstracts. Development Studies Association Annual Conference 1982. Dublin: Centre for Development Studies.

Wallace, T. 1982. "Non-farming Occupations in Chiromawa: their Significance for the Running of the Irrigation Scheme and the Impact of the Scheme on These Occupations." Irrigation in Tropical Africa: Problems and Problem-Solving. Workshop 24-25 March, African Studies Centre.

Walling, D. E. et al. 1984. (eds.) Challenges in African Hydrology and Water Resources. IAHS Publication No. 144.

Wallis, J.A.N. 1962. "Irrigating Arabica Coffee in Kenya," in Wright Rain Ltd., Africa and Irrigation. Proceedings of an International Symposium, Ringwood, Hampshire, England: Wright Rain Ltd., pp. 221-235.

Walsh, F. 1985. "Onchocerciasis: River Blindness," pp. 269-294. In, Grove, A.T. (ed.) The Niger and its Neighbours. Rotterdam; A. A. Balkema.

Wang, Jaw-Kai and Ross Hagan. 1979. "Manageability Considerations in Irrigated Rice-Production System Design," pp. 112-126. In, Honadle, Goerge and Rudi Klauss (eds.) International Development Administration. New York: Praeger.

Wang, Jaw-kai and Ross E. Hagan. 1981. Irrigated Rice Production Systems: Design Procedures. (Westview Tropical Agriculture Series, No. 3.) Boulder, Colorado: Westview Press.

Water Management Synthesis Project. 1984. Assessment of Rift Valley Pilot Rice Project and Recommendations for Follow-on Activities. WMS Report 24, Utah State University, Logan.

Water Management Synthesis Project. 1984. Rapid Mini Appraisal of Irrigation Development Options and Investment Strategies. WMS Report 23, Utah State University, Logan.

Waterbury, John. 1979. Hydropolitics of the Nile Valley. Syracuse, NY: Syracuse University Press, 301 pp.

Waterworth, J. V. 1964. Investigations in the Illushi Floodplain (1960-63). Special Report 14. Research Branch, Ministry of Agriculture and Natural Resources, Benin City, Mid West Region, Nigeria.

Waterworth, J. V. 1967. The Application of Hydrological Data to Rice Growing in the Illushi Niger Floodplain. Occasional Paper No. 8, Research Branch, Ministry of Agriculture and Natural Resources, Benin City, Midwest Region, Nigeria.

Watt, S.B. 1981. "Peripheral Problems in the Senegal Valley," pp. 167-189. Saha, Suranjit K. and Barrow, C.J. (eds.), River Basin Planning: Theory and Practice. Chichester, England: John Wiley.

Weaver, T.L. et al., 1985. Strategies for Irrigation Development: Chad/USAID. Water Management Synthesis, Report 41. Logan, Utah: Utah State University.

Webb, Patrick J. 1986. "Of Rice and Men: The Story behind The Gambia's Decision to Dam its River," pp. 120-130. In, Goldsmith, E. And Hildyard, N. (eds.) The Social and Environmental Effects of Large Dams, vol. 2, Case Studies. Camelford, Cornwall: Wadebridge Ecological Centre.

Webster, C. C. and P. N. Wilson. 1980. Agriculture in the Tropics, 2nd edition. London: Longmans.

Webster, R. 1977. Quantitative and Numeric Methods in Soil Classification. Oxford: Oxford University Press.

Weigel, J.Y. 1980. "Irrigation and Socio-Economic Systems of the Sonolé the Bakel Region (Senegal River Valley)." Purdue University. Workshop on Sahelian Agriculture, May 1980. Lafayette, Inc.: Dept. of Agric. Econ., Purdue University.

Weigel, J. Y. 1980. Irrigation et système traditionelle de culture dans la région de Bakel (vallée du Sénégal). Paris: ORSTOM.

Weigel, J. Y. 1981. "Bilan socio-économique de l'irrigation dans la région de Bakel, " Etudes Scientifiques, December.

Weigel, J. Y. 1984. "Irrigation et participation dans la région de Bakel (Vallée du Sénégal)," Développement agricole et participation paysanne. Un exemple, la politiquede l'eau en Afrique. Paris: CNRS-CEJC.

Weiler, E.M. 1979. Social Cost-Benefit Analysis of the Nianga Pilot Project. M.S. Thesis, Agricultural Economics, Purdue University, 291 pp.

Weiler, E. M. and W. E. Tyner. 1981. "Social Cost-Benefit Analysis of the Nianga Irrigation Pilot Project, Senegal," Journal of Developing Areas, 15, 4, pp. 655-669.

Weir, A. 1978. A Comparative Study of Settlement Schemes in Kenya, Malawi and Zambia. Mpongwe Pilot Project Settlement Schemes Study, Landell Mills Associates, P.O. Box 3000 Lusaka.

Weiss, M. and A. Jansen. 1976. Drought In Africa: Africa Documentation Service. Hamburg: Institut fur Afrika-Kunde.

Wells, J.C. and W.R. Norman. 1984. Sahelian Irrigated Agriculture: A Review of French Literature Sources. Water Management Synthesis II Project, Cornell University, Ithaca.

Wenner, C. G. 1970. Water Resources and Supplies within CADU's First Project Area. CADU Publication 53. Ethiopia: Agricultural Development Unit.

Wensley, Christopher and Walter, Michael. 1985. Small-Scale Irrigation: Design Issues in Government-Assisted Schemes. WMS Report, no. 39. Ithaca, New York, Cornell University, 50 pp.

West, H. W., and Grove, A. T. 1981. Land Tenure, Policy and Management in English-Speaking African Countries: with Special Reference to Arid Land Problems. Unpublished report commissioned by the United Nations University, Tokyo.

West African Technical Review. 1981. "Irrigating Borno State - South Chad Irrigation Project Transforming the Region," West African Technical Review, June 1981, pp. 93-97.

White, G. H. 1978. Environmental Effects of Arid Land Irrigation in Developing Countries. MAB Technical Notes 8. Paris: UNESCO.

White, Gilbert. 1979. L'irrigation des terres arides dans les pays en développment et ses consequences sur l'environnement, 67 pp.

Whittington, D. 1980. Water Management in Egypt: A Case Study of the Aswan High Dam. Ph.D. Thesis, University of Texas at Austin.

Whittington, D. and Haynes, K. E. 1985. "Nile Water for Whom? Emerging Conflicts in Water Allocation for Agricultural Expansion in Egypt and Sudan," In. Beaumont, P. and McLachlan, K. (eds.) Agricultural Development in the Middle East. Chichester, England: John Wiley.

Whyte, William F. 1981. Participatory Approaches to Agricultural Research and Development. (Cornell University, Rural Development Committee, Special Series on Agriculture Research and Extension No. 1.) Ithaca, New York: Cornell University.

Wickens, G. E. and White, L. P. 1979. "Land-Use in the Southern Margins of the Sahara," pp. 205-242. In, Walker, B.H. (ed.) Management of Semi-Arid Ecosystems. Amsterdam: Elsevier.

Widstrand, C. (ed.) 1978. Social and Economic Aspects of Water Exploitation. Water Development, Supply and Management, Vol. 7, Oxford UK, New York USA, Pergamon Press, 1978, pp. 279-282.

Wigley, T. M. C., M. J. Ingram, and G. Farmer. 1981. Climate and History. Cambridge, UK: Cambridge University Press.

Wilcock, D. A. 1978. The Political Economy of Grain Marketing and Storage in the Sahel. MSU African Rural Economy Program, Working Paper No. 24. East Lansing, Michigan: Michigan State University.

Wilkinson, J. C. 1978. Problems of Oasis Development, Oxford University, School of Geography Research Paper 20. Oxford, UK: Oxford Publishing Co.

Williams, C. N. and K. T. Joseph. 1970. Climate, Soil and Crop Production in the Humid Tropics. Kuala Lumpur: Oxford University Press.

Williams, O. 1981. "Irrigation Farming in the Southeast Lowveld of Zimbabwe - Retrospect and Prospect," Geography, 66, 3, pp. 228-232.

Wilsie, Carroll P. 1962. Crop Adaptation and Distribution. San Francisco: W. H. Freeman and Company.

Winid, B. 1981. "Comments on the Development of the Awash Valley, Ethiopia," pp. 147-165. In, Saha, Suranjit K. and Barrow, C.J. (eds.), River Basin Planning: Theory and Practice. Chichester, England: John Wiley.

Windram, A. F. 1983. "Small Sources Have a Large Potential. World Water, June 1983, 36 pp.

Winkel, C. 1984. Water Management Research in the Senegal River Basin - The 'Project Gestion d'Eau, ADRAO/Richard Toll. Photocopy of typed article by C. Winkel, March 1984, Richard Toll, Senegal.

Wintrebert, D. 1975. Rapport de fin de mission. Rome, Italy: United Nations Development Programme, Food and Agriculture Organisation.

Wisner, B. 1975. "An Example of Drought-Induced Settlement in Northern Kenya," Lewis, I. M. (ed.). Abaar - the Somali Drought. Emergency Report 1, International African Institute, London.

Wohlmuth, Karl. 1983. "The Kanana Sugar Project: A Model of Successful Trilateral Cooperation?" pp. 195-235. In, P. Oesterdiekhoff and K. Wohlmuth (eds.), The Development Perspectives of the Democratic Republic of the Sudan: The Limits of the Breadbasket Strategy. IFO Institut Afrika Studien, Nr. 109. Munich: Weltforum Verlag.

World Bank. 1977. Kenya: Bura Irrigation Settlement Project Appraisal Report (No. 1446-KE). Washington, D.C.: Agricultural Credit and Livestock Division, East Africa Region.

World Bank. 1978. "Distribution of Income Through the Extended Family System (abstract)." World Bank Research Program, Abstracts of Current Studies. Washington DC, USA: World Bank, Ref No.641-57, 45-46.

World Bank. 1979. The Irrigation Sub-Sector. Agricultural Sector Review, Paper 6, World Bank, Washington, D. C.

World Bank. 1980. Projet d'Irrigation du Gorgol; Rapport d'Evaluation, Mauritanie. The World Bank, Report No. 2517a-MAU.

World Bank. 1981. Accelerated development in Sub-Saharan Africa. An agenda for Action. Washington, D. C.: The World Bank, 198 pp.

World Bank. 1981. The Road Maintenance Problem and International Assistance. Washington, D.C.: The World Bank, 71 pp.

World Bank. 1982. World Development Report. International Development Trends; Agriculture and Economic Development; World Development Indicators. Oxford University Press for The World Bank.

World Bank. 1983. World Development Report. World Economic Recession and Prospects for Recovery; Management in Development; World Development Indicators. Oxford University Press for The World Bank.

World Bank. 1984. Toward Sustained Development in Sub-Saharan Africa. Washington, D.C.: The World Bank, 102 pp.

World Meteorological Organisation. 1972. Casebook on Hydrological Network Design Practice. Geneva: WMO.

World Meteorological Organisation. 1972. The Role of Hydrology and Hydrometeorology in the Economic Development of Africa, WMO Report No. 301, Volumes I and 2. Geneva: WMO.

World Meteorological Organisation. 1975. Drought and Agriculture, WMO Report No. 392. Geneva: WMO.

World Meteorological Organisation. 1976. Lectures on Forecasting of Tropical Weather, Including Tropical Cyclones, with Particular Reference to Africa. Geneva: WMO.

World Water. 1980. "Studies Define Irrigation Priorities for the Sahel," World Water, May 1980, 31 pp.

World Water. 1980. "Have Siphons - Will Travel," World Water, August 1980, 20 pp.

World Water. 1981. "A Growing Base for National Stabil ity," World Water, February 1981, 34 pp.

World Water. 1981. "Sudan Takes a Gamble on Sugar Prices," orld Water. March 1981, 25 pp.

World Water. 1981. "Umbuluzi Water Beats Swaziland's Sugar Crop Deadline," World Water. May 1981, 54 pp.

World Water. 1981. "Irrigation Challenge, Design for People, not for Politicians," World Water. November 1981.

World Water. 1983. "Manufacturing Rain for Mauritani Planters," World Water, June 1983.

Worral, G.A. 1961. "Soils of Sudan". Sols Africains 6(1). (with map at 1:5,500,000).

Worthington, E. Barton (ed.) 1977. Arid Land Irrigation in Developing Countries: Environmental Problems and Effects. New York: Pergamon Press.

Wright, E. P. 1986. "Water Resources for Humans, Livestock and Irrigation," pp. 25-37. In, Foster, L. J. (ed.) Agricultural Development in Drought-Prone Africa. London: Overseas Development Institute.

Wright Rain, Ltd. 1962. Africa and Irrigation. Proceedings of an International Symposium, Ringwood, Hampshire, England: Wright Rain Ltd.

Wright, T. L. et al. 1982. Nigeria. Manpower Needs and Training Requirements for Irrigation. London: The British Council, 117 pp. plus appendices.

Wunenburger, Jacques. 1980. "L'expérience des petits péri- mètres au Mali: Périmètres irrigués villageois, région de Kayes, Mali," Périmètres irrigués villageois: Seminaire tenu à Dakar du 21 au 23 avril 1980. Paris: SATEC, pp. 25-29.

Wyllie, D. 1979. "Systems of Cassava Forage Production for the Semi-Arid Tropics," Tropical Animal Production, 4, 1, 95 pp.

Wynn, R. F. 1969. "The Economics of Pump Irrigation from the Nile in the Sudan," Sudan Notes and Records, Vol. 49, pp. 83-103.

Yaron, B., E. Danfors, and Y. Vaadia, (eds.). 1973. Arid Zone Irrigation. London, UK: Chapman and Hall.

Yoder, Robert. 1983. "Non-Agricultural Uses of Irrigation Systems: Past Experience and Implications for Planning and Design." ODI Irrigation Management Network Paper 7e. London: Overseas Development Institute, 24 pp.

Yoshida, Masao. 1985. "Traditional Furrow Irrigation Systems in the South Pare Mountain Area of Tanzania," pp. 31-71. In, Mascarenhas, A., et al. Opportunities for Irrigation Development in Tanzania. JPR Series, No. 52. Tokyo: Institute of Developing Economies.

Yoshida, Shouichi. 1977. "Rice." In: Alvim and Kozlowski, eds., Ecophysiology of Tropical Crops. New York: Academic Press.

Young, A. 1969. "Natural Resources Survey in Malawi: Some Considerations of the Regional Method in Environmental Description," pp. 355-384, In, Thomas, M. F. and Whittington, G. W. (eds). Environment and Land Use in Africa. London: Methuen.

Yousif, H. M. 1985. An Integrated Economic-Demographic Theoretical Framework for the Analysis of the Factors Related to the Rural Labour Force in teh Gezira Scheme: A Micro Household Level Analysis. Ph.D. thesis, University of Pennsylvania.

Yusuf, A.B. 1978. Kano River Project Phase II: Rural Sociology. Specialist's Report: Hadegia-Jama'are River Basin Development Authority. (Unpublished consultant's report.)

Zaballone, G. 1980. "Place et évolution des périmètres irrigués villageois dans le cadre d'aménagements de grande extension: Présentation du projet Grand Matam (Sénégal)," Périmètre irrigués villageois: Seminaire tenu à Dakar du 21 au 23 avril, 1980. Paris: SATEC, pp. 58-72.

Zahan, Dominique. 1963. "Problèms Sociaux Posés par la Transplantation des Mossi sur les Terres Irriguées de L'Office du Niger," Biebuyck, Daniel (ed.). African Agrarian Systems, (Biebuyck, Daniel (ed.)). Oxford University Press (for the International African Institute), pp. 392-403.

Zaki, E. A. 1980. An on-going Evaluation of the Planning, Implementation, and Tenancy (Farm) Size of the Rahad Irrigation Project of the Sudan, Ph.D. Thesis, Michigan State University, 222 pp.

Zall, Linda and Russell, Orville. 1981. "Ground Water Exploration Programs in Africa," pp. 416-425. In, Deutsch, Morris et al. (eds.) Satellite Hydrology. Minneapolis: American Water Resources Association.

Zalla, Tom. 1982. "Report for the Juba River Development Project and Related Economic and Policy Issues," Mogadishu: USAID.

Zambia Ministry of Lands and Mines. 1967. Soils Map of the Republic of Zambia at 1:1,500,000. Government Printer, Lusaka.

Zikri, B. S. and M. S. El-Sawaby. 1979. "Salinity Problems and Land Reclamation in the Arab Republic of Egypt," Johl, S. S. (ed.). Irrigation and Agricultural Develop ment . London, U.K.: Pergamon Press, pp. 327-333.

Zikri, B. S. and M. S. El-Sawaby. 1979. "Studies on the Nile Water Quality before and after the High Dam and its Effects on Soil Fertility," Johl, S. S. (ed.). Irrigation and Agricultural Development. London, U.K.: Pergamon Press, pp. 335-345.

Zondervan-Droz, L. 1978. Choices in Irrigating Smallholdings in Sub-Humid Areas. Washington, D.C.: USAID (AFR/DR, AID/W), 20 pp.

Zonn, S. V. and El'Tezhani. 1983. "Genesis and Geography of Soils in the Eastern Sudan". Soviet Soil Science, vol. 15 no. 2, pp. 12-29.

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