BIBLIOGRAPHIC DATA SHEET PN-AAJ-392

ENVIRONMENTAL GUIDELINES FOR IRRIGATION

PERSONAL AUTHORS - TILLMAN, R.E.

CORPORATE AUTHORS - NEW YORK BOTANICAL GARDEN, CARY ARBORETUM

1981, 77P.
(SPONSORED BY USAID AND U.S. MAN AND THE BIOSPHERE PROGRAMME)

ARC NUMBER -
CONTRACT NUMBER - RSSA/TOA/1-77
PROJECT NUMBERS - 9311113
SUBJECT CLASS - AP10000000000

DESCRIPTORS - ENVIRONMENTAL IMPACT IRRIGATION
PROJECT PLANNING

FOR TRIAL USE

ENVIRONMENTAL GUIDELINES FOR IRRIGATION

United States Man and
the Biosphere Programme

and

United States Agency for
International Development

RSSA/TOA/1-77

Robert E. Tiillman
New York Botanical Garden
Cary Arboretum

931-1113

ENVIRONMENTAL GUIDELINES FOR IRRIGATION

United States Man and the Biosphere Programme

and

United States Agency for International Development

Robert E. Tillman

New York Botanical Garden Cary Arboretum

Millbrook, New York

June, 1981

This report was supported by funds provided in part by the Office of Forestry, Environment and Natural Resources, U.S. Agency for International Development, U.S. Man and the Biosphere Programme and the New York Botanical Garden Cary Arboretum.

contract: RSSA/TCA/1-77

project: 931-1113

TABLE OF CONTENTS

PREFACE

Until recently, many development planners viewed environmental guidelines as annoying obstacles in an already difficult and complex task. Often unrealistic, the numerous environmental guidelines commonly alienated planners and were generally not well received. In some countries, environmental considerations were viewed as luxury items in development planning which could be ignored, given the urgency of pressing national needs. The extreme view was that environmental management was a ploy of industrialized nations to decelerate economic growth in developing countries. Surprisingly, resistance to environmental review could sometimes be found in technical disciplines as well, for experts often felt that it was a biased intrusion into their area of expertise.

To a degree, these unfortunate attitudes were due to a misunderstanding of the role of environmental assessment in the development process. The concept began with a series of publications which focused on real or predicted eco-catastrophes caused by careless development procedures. Pollution, overpopulation and extinction of species were the central issues and developers were portrayed as the primary villains. The literature was sensationalized to attract attention to the world-wide deterioration of environmental quality. Activist environmental groups, formed in developed countries, were successful in causing the passage of favorable legislation and skillfully used the court systems to strengthen the position of environmental analysis in the decision-making process. Throughout the world, "environment" became synonymous with pollution, preservation and development delays.

The adversary role between development and the environment was encouraged in those early days in order to attract publicity. However, the increasing and productive interchange between environmental scientists and development planners has created a more cooperative atmosphere throughout the world. There is now a general agreement that an understanding of the environment is a key to the long-term success of development projects, although pockets of the former resistance still exists.

A significant and encouraging trend was noted during the development of these guidelines for irrigation. The terms "environmental assessment" and "management" have been broadened in development planning to include the various human aspects and interactions which are as vital to project design as accounting for climate, soil and water, but have often been neglected in the project review. Social and political considerations must be factored into this broader environmental analysis if proposed projects are to attain long-term sustainability.

In this world of unequal distribution of wealth and resources, large segments of the human population exist at bare survival levels. Continued population growth further strains the limits of available natural resources and capital, allowing for little margin of error in development planning. The most resilient environment cannot be stretched infinitely to keep pace with human population increases; therefore development and environment must be closely intertwined to maximize long-term sustainable benefits for each new commitment of scarce funds and precious natural resources. To achieve sustainability in irrigation development, there must be a cooperative exchange between a variety of disciplines, each with an important, definitive role. These guidelines rely on a multidisciplinary approach to irrigation planning simply because experience has shown that there is no other reasonable alternative.

I. GUIDELINES USES AND USERS

The guidelines and checklist were prepared for individuals who are responsible for the environmental aspects in irrigation project planning. Successful integration of the environmental component with the inputs from other disciplines requires a basic understanding of the technical factors and ecological relationships which can affect irrigation. The guidelines and checklist reflect the broadest definition of environment, including socio-economic and public health sections.

The guidelines provide a systematic approach to developing a basic understanding with or without previous experience in environmental science or irrigation planning. Ideally, the person responsible for environmental review of such projects will have a strong background in ecology or irrigation planning: technical, environmental and social. However, since the real world is less than ideal, preliminary environmental assessment often becomes the responsibility of a person without previous experience with irrigated agriculture or ecology. In this case, the guidelines are particularly valuable, offering a step-by-step approach to environmental assessment and integrated irrigation planning.

The guidelines are directed at irrigation projects of a medium to large scale, in excess of 100 hectares, since multidisciplinary studies for survey and design are required for projects of this size. The scale is consistent with current trends in irrigation project funding and based in part on the results of a study by the International Commission on Irrigation and Drainage. The generalizations from this study suggest that irrigation projects are more efficiently planned and implemented if total project size is between 1000 and 10,000 hectares with rotational units between 70-300 hectares, depending on topography (White, 1978).

While environmental review of newly proposed irrigation projects is emphasized in the guidelines, the latter can be used for assessment at any stage of development. The detailed environmental data checklist (Appendix I, pg. 65) was originally intended to supplement the guidelines, although reviewers felt that the checklist was valuable as a separate, or detachable, component of irrigation planning. In combination, the guidelines and the checklist can be used to evaluate the adequacy of irrigation planning in specific areas, such as social considerations or public health review.

A common and increasing role for funding agencies is to provide funds for environmental studies. The guidelines and environmental data checklist can be used to prepare specific terms of reference for environmental studies; in short, they are a checklist for project scoping. From the checklist, missing data sets from an irrigation project proposal can be identified and included in the terms of reference for environmental contractors or consultants.

These guidelines were prepared in draft form following an extensive literature review. This draft was discussed in the field with irrigation experts, medical advisors, ecologists, and social scientists at locations in California, West Africa, East Africa, Israel, Bangladesh and Mexico. A revised draft was reviewed by irrigation experts, field personnel, and development planners in U.S. Agency for International Development, Food and Agricultural Organization of the United Nations, the International Bank for Reconstruction and Development, United Nations Environment Programme and World Health Organization. The present form, therefore, is a synthesis of technical literature, field visitation and technical review.

Throughout the preparation period, from literature review to final draft, site-specific examples were encountered to verify or support each discussion point including positive and negative aspects of irrigation. However, rather than being supportive of a particular point, use of specific irrigation project examples are too often accusatory, either by omission or commission. Productive and well-managed irrigation projects are not limited to a select group of nations, nor are negative irrigation impacts limited to countries without extensive experience in irrigation technology. For this reason, specific projects have not been identified to support positive or negative points, except in a most general sense.

Environmental guidelines for irrigation cannot be comprehensive, brief and non-technical at the same time. Each condition presents conflicts which must be resolved by compromise. Overall, brevity was considered to be the most important feature. An abundance of excellent technical and popular references are available to supplement the material offered in these guidelines. Also, there is an annotated bibliography (page 62), given in addition to the complete citation of all the references used to prepare the guidelines. The lack of technical detail or site-specific examples in this simplistic and general approach does not deny the validity of the guidelines for assessing environmental impacts of irrigation projects.

II. OVERVIEW OF IRRIGATED AGRICULTURE

> Irrigation in many countries is an old art - as
> old as civilization - but for the whole world,
> it is a modern science - the science of survival.
> N.D. Gulhati (India)

Irrigation is an ancient art which provided agricultural bases upon which early civilizations flourished. Extensive irrigation systems were developed in Mesopotamia, Egypt, China, India and Peru that must be dated by millenia rather than decades. Some ancient irrigation channels still carry water to agricultural lands after 2000 years of constant·use. More commonly, however, those early systems are now little more than archeological artifacts near sterile soils and abandoned cities, offering stark reminders of past cultural glories. Some investigators see a close relationship between irrigation efficiency and stability of civilization in the early projects (UNESCO 1961). Present day civilizations and modern irrigation systems perhaps have a similar relationship, but on a much larger and more crucial scale. At the current scale of worldwide irrigation, declines in efficiency affect nearly every nation, especially those which must depend upon increased agricultural productivity from arid or semi-arid lands.

Estimates on the amount of cropland under irrigation on a global scale are variable, ranging from 216 million hectares (Strout 1975) to 230 million hectares (FAO 1978). However, former FAO irrigation expert C. E. Houston (1977) cites the most significant statistic by noting that nearly one half of the world's total population depends upon food production under some degree of irrigation. Since the global population continues to increase at unhealthy rates, far in excess of the increased production that can be expected from rain-fed agriculture, new or improved irrigated lands must contribute even a larger share of the world's food production just to maintain current nutrition levels.

Irrigated agriculture is increasing at a rapid rate throughout the world (Table I), yet serious food deficiencies continue to plague many developing countries where the rate of population growth remains over 2.5% per annum.

In spite of the long history and dramatic recent increases of irrigated agriculture, less than half of the land that has potential for irrigation development has actually been developed for this purpose (Table II). The estimates for land with irrigation potential are likely to be conservative. New advances in technology, such as sprinkler and trickle irrigation, can be employed on lands which were previously classified as unsuitable for irrigation. With the new technologies, water, not land, is likely to be the limiting factor.

TABLE I

Distribution of Irrigation in the World
(thousands of hectares)

Region	1961-65	1976	% Increase 1961-76
WORLD	189,100	230,000	21.7
Developed nations	38,700	50,200	29.8
Developing nations	150,400	180,300	19.9
Africa	5,900	7,700	30.5
North/Central America	19,600	23,200	18.4
South America	5,400	6,700	24.1
Asia	133,800	163,600	17.9

Berry (1980) after FAO Production Yearbook

TABLE II

Estimates of the World's Land Area Under Irrigation
in 1970 and Ultimate Potential
(thousands of hectares)

Region	1970	Potential	% Increase
Developed nations	47,900	175,300	266
USSR	11,000	100,000	809
Latin America	10,300	27,900	170
Middle East/Africa	13,700	36,200	164
Asia	133,700	254,900	91
TOTAL	216,600	594,300	174

Berry (1980)

The encouraging estimates for irrigation potential must be tempered by the realization of growth in the world population levels. Global food shortages will continue to increase until population growth is checked by design or disaster, or until food production is significantly increased. While limited increases can be expected from improvements in rain-fed agriculture, most experts look to improved or expanded irrigation for the necessary increased agricultural productivity. Data presented at the 1974 World Food Conference indicated a need to develop 23 million hectares of new irrigation projects between 1975 and 1985 to meet the world food requirements (White, 1978). The estimated costs for such ambitious increases are staggering; 25 billion* dollars to "improve" 50 million hectares and 40 billion dollars to develop new irrigation (Houston 1977). Since this estimate was in 1975 dollars, a more realistic figure for the new irrigation is 150 billion dollars (White, 1978).

National governments, international lending organizations, and donor agencies are devoting massive sums to the expansion or renovation of irrigation, but these fall well short of the 4 billion dollar per year expenditure necessary to meet the 1974 World Food Conference requirements. Irrigation is the largest single component in agricultural loans from the International Bank for Reconstruction and Development (World Bank). The United Nations Development Programme has made significant contributions to FAO water projects, principally in irrigation (Houston 1977). The U.S. Agency for International Development committed over one billion dollars for irrigation projects between 1952 and 1979 and the annual commitment is increasing each year (PCI 1980).

The international pace to expand or improve irrigation is not expected to abate during the next decade. However, certain elements of irrigation development will change, or must change, if world food needs are to be met. Since most of the suitable lands have been utilized, irrigation projects will push into marginal areas, which present increased difficulties in soil fertility, water quality, health hazards and social adjustments. Within these areas, social and ecological systems are less resilient and more easily damaged by poor planning and design, yet less is known about these systems. Decisions for development in marginal areas, especially in irrigation, is based on extrapolations or experiences in other areas, rather than current site-specific research; too often this causes social and environmental problems that negate all expected economic benefits. In recognition of these problems, irrigation development must extend analyses beyond strict economic projections if these projects are to provide expected long-term benefits.

---

*Billion = 1×10^9

III. BENEFITS OF IRRIGATION

While many recent accounts of global irrigation paint gloomy pictures of ecological and economic disaster, very few overviews describe the varied benefits of irrigated agriculture. As reliable data are lacking on worldwide production from irrigation, benefits can be summarized from the success of individual projects. Benefits may be direct (yields per hectare or contribution to gross national product) or indirect (improved local nutrition, higher standard of living). As with most development projects, the direct economic benefits can be more easily calculated. Modern irrigation planning seeks to maximize both direct and indirect benefits while minimizing economic, social and environmental costs.

The agricultural benefits of irrigation are most apparent and fall in the following categories:

- Higher yields per unit of land;
- Higher yields per unit of water;
- Longer growing season;
- Protection against drought;
- Reliability of water supply;
- Erosion control;
- Improved agricultural management (seeds, timing, fertilizer, pesticides, machinery).

Most irrigation systems are established to improve yields per unit of land. Obviously, no set rate of improvement can be expected by converting from rain-fed to irrigated agriculture. The amount of increase will depend upon many variables, including climate, soil, irrigation technique, and type of farm management and experience. However, fivefold increases in production levels are not uncommon where irrigation has replaced shifting agriculture. These increases may not all be directly attributed to irrigation, since new seeds, fertilizers and biocides are often a part of the conversion. Even with the higher yields with irrigation, the potential for further improvement still exists. In a study by FAO in a developing country, differential yields were measured between research stations, farm demonstration plots and the average farm field (Table III). A glass seen as half empty may appear as more discouraging than one seen half full. To many, the differential results demonstrate a marvelous opportunity to bring the average farm up to the potential shown in the research plots, rather than being forced to exploit new lands for more agricultural products.

Rain-fed agriculture can waste water in that rainwater may run off or percolate through the soil so rapidly that it is of no value to the crops. Irrigation, if properly managed, can apply water in measured amounts to match crop water requirements. Yields per unit of water can be significantly improved in areas where rainfall tends to be brief and torrential.

TABLE III

Potential Yield Improvement Through Management
(units/acre)

Crop	Research Station	Farm Demonstration	Average Farm
rice (paddy)	50	40	15
cotton	35	28	8
maize	100	80	11
wheat	60	40	9

White (1978, after FAO 1969)

Irrigation does extend growing seasons in areas where the duration of rainfall is limited to certain months of the year. The brief and highly variable rainfall in arid and semi-arid regions is not of sufficient duration to permit successful growth of any but the most drought-resistant crops. The short rainy season in these areas is extended by irrigation so that one crop may be grown to successful harvest. In some areas, a growth period adequate for double or triple cropping is possible, if soil moisture can be maintained by irrigation for a longer period. For instance, in the subhumid tropics, irrigation can supplement the annual rainfall, so that a second or third crop may be grown, thereby increasing agricultural potential without expansion to virgin lands. Irrigation can be very beneficial in areas with bimodal rainfall patterns, such as parts of East Africa, where it effectively connects the two rain periods into one growing season and permits the culture of higher value crops.

Temperature is another factor which can be modified through irrigation. For instance, water applied by sprinkling has prevented frost damage on fruits, vegetables and flowers (Israelson and Hansen 1962). The evaporative cooling from sprinkler irrigation has been used to prevent early flowering in citrus groves, reducing the danger of late frost damage (Lipe et al. 1977). Irrigation can also be used to elevate soil temperatures and control plant zone humidity when those factors threaten crop growth.

Farmers appreciate the crop safety factor provided by irrigation. Nearly every farmer faces the prospect of drought occurring during a critical period in crop development. Drought causes severe agricultural impacts whether it is long-term, such as that which occurred in the Sahel in the seventies, or the severe short-term drought of 1980 in southern United States. With irrigation, the farmer is usually able to salvage all or part of his crop when dry spells occur.

In the same vein, irrigation reduces agricultural risks by eliminating the capriciousness of rainfall patterns. This is especially important in arid and semi-arid regions where the rainfall is most variable. Research has shown that during certain stages in plant development, soil moisture becomes very critical. As the variability of the rainfall increases, the probability that a dry period will coincide with a critical growth stage increases. The farmer can reduce his risk by staggering planting dates of the crop, which creates the problems of different harvest dates, or by investing in supplemental irrigation to maintain proper soil moisture during the critical growth stages. With irrigation, farmers can commit a larger portion of their resources and have a reasonable expectation of a larger return on their higher investment.

Irrigation should provide indirect benefits in erosion control. Croplands under irrigation are arranged to control water movement through the use of levees, bunds, ditches or land leveling. In sprinkler or trickle systems, water is applied at rates too low to cause erosion. In addition, irrigated croplands are more likely to be covered by water or vegetation for longer periods than rainfed farmland, thereby reducing soil losses by wind erosion. In well-managed irrigation systems, there is a greater concern for watershed protection, since upstream soil erosion can clog irrigation equipment. Watershed management does extend soil protection beyond actual cropland, benefiting the entire ecosystem.

Finally, indirect agricultural benefits are derived from irrigation projects due to the use of more sophisticated management techniques. Irrigators are more aware of the value of improved seeds, fertilizers and pesticides. In some cases, fertilizers and pesticides can be applied with irrigation water, reducing labor and costs. Farmers can time crops better so that they are in the same stage of growth right up to harvest time. This allows for more efficient use of fertilizers and pesticides as well as producing more uniform harvests. In some cases, the timing of irrigated crops can be altered so that periods that require high labor inputs, such as transplanting, weeding or harvesting, will coincide with times of local labor surpluses.

High value or high yield crop varieties that require higher water inputs may be selected when irrigation is available. In addition, the extended season with adequate water permits crop rotations which benefit soil fertility, thereby encouraging higher yields without additional fertilizers.

In addition to agricultural benefits, irrigation can also contribute to public health and social benefits at local levels.

Worthington (1977) discussed the positive aspects in the field of public health. In many areas, irrigation projects have water supplies for domestic uses, and in some cases have even piped water into villages, although this aspect is too often neglected. Since machinery and technical personnel are in the area during construction for irrigation systems, the cost of an additional system for domestic water is minimal.

Often, large irrigation projects require resettlement of human populations. In this case, public health benefits can be created through new and improved housing, safe water supplies, and provision of village health services. Recently, there has been a special increased concern for the displaced populations that is reflected in improved relocation planning.

In areas where malnutrition is a serious problem, the development of irrigated agriculture, together with livestock raising and fish culture, can improve nutrition levels by increasing the quantity and quality of available foodstuff, particularly protein (Worthington 1977). Standards of living, raised by increased employment opportunities and income levels associated with irrigation, also elevate health standards. Ample employment and food availability create an "appetite for health" which becomes an important aid in developing local public health programs (Worthington 1977). Unfortunately, however, health services rarely meet the increased need and higher morbidity levels of water-related diseases created by the irrigation project, which offsets the potential health gains.

Socio-economic benefits are widely cited in irrigation project proposals, although rarely verified by post-project evaluations. These have great potential, especially if considered carefully in initial planning stages.

Worthington (1977) lists six potential social benefits of irrigation development:

- national economic efficiency
- gaining of foreign exchange through export crops
- sedentarization of nomadic people
- drought damage prevention
- stabilization of agricultural systems
- modernization of rural economy.

Successful irrigation projects, and even those not so successful, do contribute to national economic efficiency. Most developing countries are obliged to import food to feed increasing populations, so any increase in agricultural production is considered a positive economic feature.

When irrigation enables a developing nation to grow a cash crop for export, valuable foreign exchange credits are earned to use for other development needs, usually energy imports. Cash crop exports of groundnuts in West Africa, high quality rice in Pakistan or cotton in North Africa contribute a significant portion of national foreign exchange.

Sedentarization of nomadic people through use of irrigation provides better opportunities for health services and education, although social disruptions and loss of cultural identities are offsetting impacts. Agricultural systems are stabilized in that crop yield is more uniform and predictable with irrigation. Even if the end results do not meet project expectations, average annual yields do not vary as much as those under rain-fed conditions.

Perhaps the most significant social benefit of irrigation development is the modernization of rural economies. With the massive migrations of the rural poor to urban centers in Latin America and Africa, modernization of rural areas is the only hope to stem the tide. Irrigation projects invariably bring new forms of energy in the form of electric transmission lines, hydropower or petroleum engines. While most of the energy is used for agriculture or industry, small portions are often diverted for domestic use or for village centers. Transportation routes are normally improved to move agricultural products to markets, thereby affording greater opportunities to establish trade with urban centers for other types of goods. Irrigation projects normally require an infrastructure to construct and operate the system and the same one can be used to provide social services, as in education and health. Development of irrigation often forces a rural area away from a barter economy into a cash economy, so that savings do not have to be in the form of wasteful material goods or destructive livestock concentrations. The romantic view of idyllic rural or nomadic life styles is often a cruel myth, perpetuated by the urban elite, who can escape city pressures and confines for brief and pampered excursions into "primitive" and colorful areas. There are few pleasures of rural living without electricity, medical services or transportation. Irrigation projects can and often do provide those essentials to rural economies upon which they function, even if only at the most basic level.

IV. ENVIRONMENTAL PROBLEMS OF IRRIGATED AGRICULTURE

The development of irrigated agriculture produces many, far-reaching ecosystemic changes. Some, as noted in the previous chapter, benefits human populations, while other changes threaten the long-term productivity of the resource base. The undesirable changes are not solely restricted to increasing pollution or losses of habitat for native plants and animals; they cover the entire range of environmental components, such as soil, water, air, energy, and, of course, social systems. In this section, the term "environment" is continued in its broadest context, of which man and man's interactions are an integral part.

Since 1970, every type of development project has been subject to much closer environmental scrutiny, and the requirements for environmental analyses are becoming more stringent. This closer inspection has revealed many serious problems, which heretofore were unknown except to a small contingent of scientists and agriculturists. The global record shows that due to soil deterioration, massive tracts of irrigated cropland are going out of production at nearly the same rate as the amount of new irrigated lands are being added (Biswas et al. 1980). In some areas, detrimental changes in water quality downstream from irrigation projects has rendered it worthless to other users. Since the degraded water courses often cross national borders, this has created international tensions. More recently, irrigation projects have been implicated in severe socio-economic disruptions, particularly in areas of forced resettlement and public health. Due to irrigation, unprecedented increases in water-related diseases, such as malaria and schistosomiasis (Bilharzia), have focused international concern on irrigation development by the World Health Organization (WHO) and the United Nations Environmental Programme (UNEP).

Equally apparent is the fact that most of the serious problems could have been mitigated or eliminated had environmental considerations been an integral part of the planning and design of irrigation projects. In the past, irrigation planning and design was performed by technical specialists, normally civil or agricultural engineers and economists, who worked mainly within their specialities. Systems were structurally sound, capable of delivering water to cropland, and built at reasonable cost. Unfortunately, soils were not always analyzed for long-term potential and water was viewed as a benign substance. People were generally disregarded, except as economic units for labor, markets or income generation. Social, cultural or public health data were rarely collected in depth, or, if already available, not factored into planning or design. Since irrigation involves far more complex environmental and social interactions than simply providing a system to deliver water to potential cropland, the projects which ignored these vital interactions were destined for serious trouble. The problems were not often publicized, perhaps due to an attitude voiced recently by a development officer who remarked, "Development agencies do not have failures, just partial successes." In view of the present world food situation, "partial successes" which threaten long-term productivity or the general welfare of the people in the project area cannot be tolerated.

The environmental problems outlined in this section have been discussed in detail by Worthington (1977), Man and the Biosphere Programme (White, 1978) and the United Nations Secretariat Report on Desertification (1977). While presenting a gloomy picture of irrigation-related problems, there is an encouraging feeling that the problems can be resolved or eliminated by:

- Detailed pre-proposal inventories of soil, water, biological resources, public health and social structures;
- Multi-disciplinary planning and design;
- Close communication and coordination between engineers, agronomists, geographers, public health specialists, hydrologists, geologists, sociologists and planners.

The experts assembled by the international agencies to prepare the excellent reviews of global irrigation suggest that world food shortages can best be resolved by rejuvenating and increasing production on existing irrigation systems rather than developing new areas. Studies have shown that most of the irrigation projects in operation can be upgraded to improve yields. Renovation of water delivery systems or improved extension training for farmers cause less social disruption than expansion to new lands and is less expensive per unit of increased production. Improvement to existing projects and training farmers as better water managers should receive top priority in irrigation funding and development.

The environmental impacts of irrigated agriculture can be divided into five primary categories;

- Soil modifications;
- Changes in ground and surface water;
- Socio-economic impacts;
- Public health;
- Effects on flora and fauna.

The categories here are established for simplicity in description, for in reality the degree of interrelation between the topic categories becomes more complex with each new research report (Worthington 1977, United Nations Secretariat 1977). Notwithstanding the complexity of the problems, a general, non-technical discussion is necessary to understand the reasons for these guidelines for irrigation development.

A. Soil Modifications

The most common and most serious soil problems caused by irrigation are water logging, salinization and alkalization. To a degree, almost every irrigation system in the world must contend with the prospects of water logging or salinization.

Water logging is a common feature of a large number of irrigation systems and can be especially severe in low-lying plains. This occurs when ground water saturates the plant root zone - the layer of soil that contains most of the plant root systems. Large pores between soil particles, normally filled with air, become saturated with water, preventing an exchange of oxygen between the plant roots and the soil. In some places, water logging is a natural phenomenon during all or part of the year. Natural seeps, or swamps, are places where the water table (the upper level of the ground water reserve) is at or near the surface of the land. River flood plains often have extensive water logging during the flood season when the ground water receives water at a faster rate than is being used or discharged to surface water bodies.

With irrigation, water added to cropland in excess of crop requirements and soil drainage capability will also elevate the ground water levels. While this type of over-application in poorly managed systems is common, it is also important to note the amount of water that seeps out of water delivery systems into the ground water. Unlined reservoirs, canals and ditches lose a great deal of water through seepage. Water losses between the primary source and the farm fields commonly exceed 50% of the total water volume in unlined systems. This can produce a spectacular rise in the water table, normally several centimeters per year, but in a few instances, several meters per year (White, 1978).

When the water table reaches within 1-2 meters of the soil surface, the rise becomes more significant. At this point, the ground water adds to the moisture in the root zone through capillary action, the upward movement of water through soil pore spaces. Capillary water increases the saturation in the root zone to the point that oxygen exchange is hindered. While this is a serious agricultural problem, a more severe effect can occur when the ground water is saline.

Soil salinity, another complex irrigation problem, is seriously affecting the productivity of one-third of the world's irrigated land (El-Ashry 1980). Salinization is a factor in all agricultural areas, but is most commonly associated with arid or semi-arid lands. Soil salinity is a principal focus of irrigation research and has been a major subject of numerous publications and international conferences (Boyko 1969, FAO/UNESCO 1973, Dregne 1977).

For irrigated lands in arid and semi-arid regions, where salinity problems are most common, even good quality irrigation water (200 ppm soluble salts) can add 0.2 tons/ha of salts with a normal water application of 10,000 m^3/ha/year (Massoud 1977). With irrigation water of higher salt content, the risk of soil salinization increases. When the saline water is applied to the soil, most of the water is used by plant transpiration or lost through evaporation from soil and plant surfaces, leaving the salts behind in the soil. Since high salt concentrations in the root zone can interfere with the movement of soil water into the roots, plants begin to wither and die when the concentrations become sufficiently high. There is a great deal of variation in plant tolerance to soil salts. Plants growing naturally along ocean coasts can tolerate high salinities, while most agricultural crops are relatively sensitive to salt injury. However, there is also wide variation in salt tolerance of crop plants. Barley, cotton and wheat, for example, are more tolerant than corn or beans (Bernstein 1964). Agronomists also find that some genetic varieties of crop species are more salt tolerant than more common varieties and offer potential for use in the more saline soils. New irrigation techniques have promising results for the use of saline irrigation water (Hardan 1977, Goell _et al._ 1977).

Soil salinity can also occur due to salt concentrations encountered in the soil. Some soils are derived from salt-bearing parent material, but in temperate or humid zones, the rainfall is sufficient to leach the soluble salts out of the root zone into the ground water flows that eventually reach the ocean or are diluted by larger flows of non-saline water. However, in arid or semi-arid regions, the scanty rainfall is not sufficient for adequate leaching and the salt remains at or near the plant root zone. The soils derived from salt-bearing parent material are not usually considered for irrigation since the cost of remedial action for successful agriculture would exceed the economic benefits.

The problem of soil salinity becomes more serious when coupled with water logging. When this occurs, secondary soil salinization can render the lands useless for crop production. As the water table rises under water logging conditions, salts concentrated beneath the root zone are dissolved and carried to the root zone or to the surface and are deposited as the water is transpired or evaporated.

Alkalization, or secondary soda salinization, is an especially serious problem of irrigated soils. This process is caused by alkaline ground water and/or by diluted soda-carrying irrigation water. The sodium in these waters becomes concentrated in the upper soil layers, far in excess of the normal ratio between sodium and calcium or magnesium. The sodium ions attach to clay particles in the soil, causing them to disperse when wet, rendering the soil nearly impermeable to water (White, 1978). In addition, a high concentration of sodium ions in the soil may cause sodium to be absorbed by plants in toxic quantities (Massoud 1977). Sodification, or alkalization, may also be caused by irrigation water with a high bicarbonate content. The bicarbonates precipitate calcium and magnesium, thereby increasing the percentage of sodium in the ion exchange between plant and soil (U.N. Secretariat 1977). Alkalinity is a more serious soil problem than other salinity problems in that it is far more detrimental to the soil and more difficult to remedy.

Irrigation may change the texture of the soil (Yaalon and Yaron 1966). Unfortunately, very few studies have examined soil changes over a long period of time, except for some physico-chemical studies in salinity-prone areas. Also, it is difficult to separate the effects of irrigation from the effects caused by repeated workings of the soil or the addition of agricultural chemicals to increase fertility.

Soil texture can also be changed by the tillage practices for certain types of irrigation, as often occurs with non-irrigated agriculture. The soil is worked so often and so thoroughly that fine particles at the surface are exposed to wind erosion. As the small particles are blown away, the texture becomes more gravelly. On the other hand, sediments cleared from irrigation ditches are normally added to the fields, thereby changing texture and surface elevation which may alter irrigation efficiency.

Nutrient leaching is another effect of over-irrigation. Important nutrients, especially nitrates, can be leached out of the root zone. As excess water is applied, either by mis-management or for leaching dangerous salts, the nutrients are removed and must be replaced by chemical fertilizers, organic matter or certain types of crop rotations. The leached nutrients not only impoverish the cropland, but also cause serious environmental problems in downstream water courses and domestic water supplies.

Coastal swamps, drained and irrigated for rice production, face a very grave soil problem. The sulphurous compounds in these soils develop from anaerobic decomposition (without oxygen) as they are covered by water. The compounds oxidize quickly if exposed to air for extended periods, producing acid sulphate soils which are too acidic for crop growth. This type of soil degradation is quite common where estuarine mangrove forests have been cut and drained for paddy rice. The irrigator must cope with salinity problems, and also must take care not to drain the fields completely. Acid sulphate soils can be corrected, but only after careful freshwater flushing over several growing seasons.

There are few hard and fast rules for judging a soil's response to irrigation. Different soils will react in different ways, depending on climate, quality of irrigation water, amount of water applied and the method of application. The most serious soil-related irrigation problems stem from the lack of adequate drainage. It seems to be an international tendency to overestimate the natural drainage of the soils in a proposed irrigation project and to underestimate the necessity of artificial drainage systems. Most experts agree that inadequate drainage is the most serious technical flaw in irrigation design and construction.

In order to assess drainage and potential soil problems, planners must have reliable data from recent soil surveys and tests available for expert analysis. Yet, in many countries, it is not difficult to find irrigation projects funded by international organizations with extensive experience in irrigation development in final stages of construction, or in actual operation, without the benefit of a series of soil tests. These guidelines wish to avoid such environmental shortsightedness.

B. Water Quality

Water for irrigation can cause negative effects while going into and out of the fields. Irrigation planners are usually most concerned about the amount of water available for agricultural use. Very few irrigation plans are remiss in assessing the flow rates of surface sources, size of required reservoirs or the extent and location of ground water supplies. However, equal attention is not given to the quality of the irrigation water or the effects of irrigation return flows (water drained from the field to streams or ground water reserves).

Most irrigation water supplies contain salts to some degree, and the concentrations may vary seasonally. Whether or not the salts accumulate to dangerous levels depends upon the soil type, climate, crop requirements, amount of water applied and the method of application. For instance, water of higher salinity can be used more safely on sandy, well-drained soils than on finer-grained soils. Problems with saline irrigation water are less likely to occur in areas of higher rainfall, since the wet season rains help to leach salts out of the root zone. And finally, sprinkler and trickle (drip) irrigation can use more saline water since water control is more precise and lower water volumes are used per crop.

In spite of the ease in testing potential irrigation water for dissolved solids, new irrigation projects continue to be plagued by unforeseen salinity impacts. In some cases, the salinity problems may develop because planners did not anticipate changes in water quality caused by upstream users. Water salinity levels can increase in dramatic fashion due to upstream misuse. For example, salt concentrations in the Colorado River flowing into Mexico nearly doubled (from 800 mg/l to 1500 mg/l) between 1960 and 1962 because saline ground water was pumped into the river from an Arizona irrigation project and river flow was reduced by the closure of Glen Canyon Dam in Utah (El-Ashry 1980).

Salts are not the only difficulties in irrigation water. Toxic chemicals, such as boron and arsenic, and biocides may be present at dangerous concentrations. In addition, water is a well-documented vehicle for human and animal pathogens, including viruses, bacteria and protozoans capable of producing epidemics of serious diseases, such as cholera, shigellosis and infectious hepatitis (Sorber 1975, Katzenelson et al. 1976, Feachem et al. 1977) Various agencies have established water quality criteria for irrigation, most notably the U.S. Department of Agriculture (1954), Food and Agriculture Organization of the United Nations (Ayers and Westcot 1976) for agricultural standards, and World Health Organization (1973) for disease control. How often these criteria are used to evaluate irrigation water in developing countries remains an unanswered question. Until international lending agencies begin to require closer attention paid to international standards, unsafe water will be applied to irrigated crops, threatening the ecological foundations of the project area.

The effects of water quality on irrigation are serious, but not nearly so serious as the effect of irrigation on water quality. These effects can be grouped into the following categories:

- Impoundments;
- Diversion;
- Ground water pumping;
- Return flows.

There is no question that the published literature on the environmental effects of large and small impoundments is well done. Little can be added to the excellent reports by Favar and Milton (1972), Ackermann et al. (1973), Freeman (1974), Odinga (1977) and Panday (1977). The environmental consequences of artificial impoundments which are highlighted in the various reports have focused closer attention on ecological impacts of dam construction. Large impoundments are becoming increasingly difficult to finance without lengthy and detailed environmental studies. These projects are financed as multi-purpose reservoirs, used primarily to generate hydroelectricity, while irrigation, fisheries, recreation and flood control are added as secondary uses to bolster benefit/cost analyses. Moreover, large dams are becoming so costly that single organizations, especially in developing countries, are unable either to provide the necessary funding or willing to accept sole responsibility. With a multi-agency funding approach, environmental considerations usually receive high priority and are included in planning and design. For these reasons, a discussion of the environmental impacts of large impoundments is eliminated and interested readers are referred to the cited literature.

The environmental effects of irrigation water diversion are primarily related to the portion of water that is undiverted. The water allowed to pass by a diversion structure is not adequate to maintain pre-diversion ecological balances. Adjustments are made in downstream ecosystems by the plants, animals and humans that rely on the water flow. Generally, ecosystem adjustments are proportional to the percent of water diverted, although some types of ecosystems are less sensitive to water volume changes. The reduced flows affect downstream plant and animal populations in terms of numbers and biomass. Species compositions usually shift toward those species with a wider range of habitat tolerances and away from those species with restricted requirements, such as most endangered species. Some species, usually those with less aesthetic or economic value to humans, will profit from reduced flows and will increase their population levels, to the detriment of the ecosystem.

Given the increasing use of streams and rivers, downstream deterioration of water quality is expected. The degree is related to several factors, including quantity and persistence of contaminants, biological systems present and the volume of water available for dilution. Water diverted for irrigation is not available for dilution and pollutants added to the water course below the diversion point, such as municipal and industrial wastes, will be more concentrated. Therefore, acceptable levels of pollutant discharge before diversion may reach unacceptable concentrations downstream without increasing the amount of discharge.

Fish are most severely impacted by diversion, and downstream fisheries are consequently reduced. The decreased water volume and higher concentration of pollutants can eliminate fishing potential well beyond project limits. Reduced freshwater flows can alter the productivity of the rich coastal and estuarine ecosystems. In estuaries, lower freshwater volumes from rivers will change the salinity balance of the system. The interface between freshwater and sea water will move inland, changing the distribution of fish and altering the breeding patterns. The changes are usually detrimental to the productive fisheries.

Diversion from rivers can also produce downstream health hazards. Unfortunately, rivers are common recipients of untreated sewage and domestic wastes. During dry seasons, the river flow can be so low that large stretches become stagnant pools of poorly diluted wastes which provide breeding areas for vermin and disease vectors. If flows are further depleted through diversion, the river is unable to flush the wastes for longer periods of time. The situation becomes acute when the rivers are used for domestic water by the rural and urban poor.

Humans and organisms other than fish can be impacted by the changes in estuarine salinity caused by diversion. The saltwater/freshwater interface moves inland, increasing the salinity of river and groundwater. Salt-intolerant native and cultivated plants decline in productivity when salinity values exceed their tolerance levels. Water, once used for drinking, can become too saline for humans and animals, forcing socially and ecologically disruptive migrations.

Groundwater pumping for irrigation creates problems when the pumping rates exceed the recharge rate of the groundwater reserves. Groundwater levels go down, forcing users to make deeper and deeper wells for water supplies. The drop in the water table may be quite precipitous, up to one meter per year (Adler et al. 1981). Domestic and agricultural users must spend more money to extend wells and use more energy to pump the water from greater depths. Two serious side-effects of groundwater depletion are subsidence and saline water intrusion in freshwater aquifers. Subsidence occurs when lands lose elevation as liquids (oil or water) are removed from sub-surface reservoirs. Houston, Texas and the San Joaquin Valley in California have experienced severe subsidence problems (Adler et al.1981).

In some instances, extraction of groundwater may cause intrusion of sea water or brines into freshwater aquifers. This is common in coastal aquifers and should be expected to occur sooner or later when water is removed by pumping (Hotes and Pearson 1977) As the freshwater is pumped, water from the sea or estuaries moves through the soil, causing increased salinity in the aquifer. Reduced pumping or adding more recharge water may reverse the trend. Wells in coastal aquifers should be monitored to detect increasing salinity at early stages before serious soil problems occur.

In some areas, deep groundwater reservoirs have been capped by geologic events which no longer permit recharge of the reservoir. These "fossil water" sources may be very large and can be tapped, but once used, the water is gone forever and no potential for renewal exists, except at great expense. Thus, reservoirs without natural recharge should be kept as emergency sources and used with caution. Long-term projects should not be dependent on non-renewable water sources.

Increased attention is being given to adverse effects of irrigation return flows. Many areas, such as the western United States are experiencing serious problems. As demand for freshwater increases, competing users will demand closer control of the quality of irrigation return flows. Of the water used for irrigation, 40-80% is a consumptive use in that the water is evaporated, transpired or incorporated into plant tissues (Hotes and Pearson 1977). The remaining 20-60% leaves the fields as surface run-off, percolates through the soil to groundwater or is removed by artificial drainage systems. As expected, the quality of the non-consumed water has been significantly altered. Since none of the salts are lost by evapotranspiration, the mineral content of soil and drain water is much higher, therefore more saline. The mineral concentration of soil and drain water in irrigation areas ranges from 2 to 10 times greater than the incoming irrigation water (Hotes and Pearson 1977). The soil water eventually moves to a water course by horizontal groundwater movement or through interceptor drains, thereby increasing the salt load of the water course. If diversion of water is occurring above the point where irrigation return flow enters, the total salinity increase caused by flow reduction (diversion) and salt addition (return flow) is significant and increases the dangers of salinity for downstream users, including irrigators. Several studies in the United States have focused on the increase in salinity due to irrigation. Eldridge (1963) collected data on five projects showing a sizeable increase in hardness of river water, attributed to high total salts from irrigation sites (Table IV).

TABLE IV

Total Hardness of Five Irrigation Sites
(mg/l as $CaCO_3$)

Location	Above irrigation	Below irrigation
Rio Grande, Texas	111	631
Yakima, Washington	33	134
Sunnyside, California	40	299
Arkansas River	212	890
Sutter Basin, California	72	480

(from Hotes and Pearson 1977)

Another major concern relating to irrigation return flows involves agricultural biocides: chemicals used to kill agricultural pests such as insects, fungi, worms and weeds. Irrigation provides a conducive habitat for insect breeding, and the presence of moisture and succulent crops lures a wide range of insect pests to the crop sites. Weeds also invade irrigation plots to take advantage of improved soil moisture regimes. To combat the plant and animal pests, farmers employ herbicides and insecticides at alarming rates. In the San Joaquin Valley of California, an intensely irrigated agricultural region, the annual pesticide application was 22 kg/ha for 1.7 million hectares of cropland (Li and Fleck 1972). Samples taken from sub-surface and surface drain effluents showed concentrations of chlorinated hydrocarbons up to 132 ppb (parts per billion), although most compounds were under 5 ppb (Li and Fleck 1972). The researchers concluded that the pesticides from agricultural run-off did not have significant adverse effects upon aquatic environments, but urged a greater attention to alternative methods of pest control. If the concentrations of biocides can reach a point to merit scientific concern in a region where the sales and applications of pesticides are under strict control, the problem may be more severe where the mixtures and applications are not subject to legal restrictions.

As with biocides, irrigation normally requires frequent applications of fertilizers to maintain soil richness under continuous cropping practices. As noted in the section on soil problems, the nutrients in fertilizers can be leached by the irrigation water into the groundwater or are carried away by surface or sub-surface drains. Irrigation return flows often exceed threshold nitrate and phosphorus limits for most organisms (Hotes and Pearson 1977). If added to an aquatic environment, the high concentrations of nitrates and phosphates contribute to eutrophication, undesirable algal blooms and waterweed proliferation.

A more serious problem with excessive fertilizer use, particularly those rich in nitrates, is the possible contamination of groundwater supplies for domestic use. In the coastal plain of Israel, the overall average nitrate concentration in wells rose from 16 mg/l in 1955 to a point where 50% of the wells were above 45 mg/l, the maximum allowable standard for human consumption (Saliternik 1973). The primary contributor to these increases of nitrates in the groundwater was irrigated agriculture. Commoner (1971) reported similar increases in nitrates in drinking water supplies in the midwestern United States. Excessive nitrates can cause methemoglobinema in infants.

Water quality of irrigation return flows is a very serious problem. Studies are just beginning to identify the impacts of high volumes of these low quality waters. The impacts can be reduced by better water management, improved agricultural practices and proper planning at the earliest possible stage of project review.

C. Human Impacts

There are some experts who argue, with good reason, that the socio-economic impacts of irrigation are more serious than its effects on the physical environment. While irrigation can be beneficial (see Chapter III), recent studies have shown a distressing series of social and economic ills can result from irrigation development (Johl 1980, Ehlers 1977, Bharara 1977, Steinberg et al. 1980a, 1980b). The extent of these negative social impacts, apart from public health factors, is beginning to receive more attention in irrigation planning. Irrigation planners must address the human factors, while developing the broadest base of community support through the participation of community leaders in the planning process.

A brief discussion of irrigation impacts on human activities can be organized into four separate, but interrelated, categories:

- Human settlement patterns;
- Socio-economic functions;
- Social organizations;
- Community participation and support.

For brevity, the categories and discussions are limited to major points and are not intended to be either inclusive or comprehensive.

Human Settlement

Patterns in irrigated croplands are determined by environmental or technological constraints, such as location of water sources, soil characteristics, topography, irrigation method and/or water delivery system, while land ownership or tenancy is influenced by human factors. Rarely, if ever, can the land patterns required by irrigation projects be superimposed on existing land use or ownership patterns without a need for change. Some land holders or tenants will be displaced to provide space for the physical facilities of the project: reservoirs, pump stations, buildings or water conveyance structures. Existing field configurations or land uses may not be compatible with the proposed project, and boundaries or uses must be altered to meet the needs of system design. While the changes may provide economic benefits due to increased irrigation efficiency, or increased yields, they are socially disruptive, especially to those displaced. This is particularly true in developing countries where small plots and land tenancy are common characteristics. In addition, property boundaries may not be registered formally and land ownership is not protected by legal title. Often, land is used traditionally without any claim to ownership, as by migratory herdsmen. In the extreme case, land ownership is held in common by a clan, tribe, village or extended family and is used or apportioned by a leader or council without official sanction from the national government. In some countries, land without title is considered public land and present users are without legal rights. In other countries, governments are making serious efforts to resolve the land tenure in an equitable fashion before development proposals increase the value of the land.

Since irrigation systems are expensive, projects are not likely to be feasible unless most of the cropland in the command area (land which might be irrigated by the system) is actually placed under irrigation. Farmers are forced, economically or by legislation, to participate as irrigators. In order to meet the increased farming costs required with irrigation, the farmer must produce increased yields of high value crops, often forsaking the culture of more traditional crops or livestock. Land uses, such as grazing, fallow or woodlot, which may be more socially or culturally appealing to the farmer, are no longer feasible options and the farmer becomes more closely bound by land use decisions of a larger social unit in which he has less influence. If the new land uses are not dramatically more beneficial to the farmer, resistance to the project or the project managers may increase to the point that efficiency and productivity are reduced.

The type of land tenure within the command area creates social problems. The costs of irrigation and the labor required to maintain the systems are borne by the irrigator, while the value of increased yields may be distributed to others, usually the landlords. If irrigation projects are established in regions with a high percentage of tenant farmers, the owners enjoy increased profits without incurring additional costs (Steinberg _et al_. 1980a). The increased value of the irrigated land further benefits the landowner without equal compensation to the tenant. In this way, irrigation can increase the economic disparity between classes unless land tenure considerations are included in the planning process.

Resettlement of dislocated populations has been the most extensively studied social impact of irrigation. Large multipurpose reservoirs have caused the relocation of thousands of people (Kassas 1980). The increased disease, malnutrition and social unrest stemming from these mass migrations were widely publicized, and resettlement planning has been vastly improved. However, small-scale relocations common to most irrigation projects do not receive equal concern. Farmers who lose all or part of their cropland for conveyance structures or pumping stations are not likely to be compensated fairly for their loss. Without financial aid during the period of temporary resettlement while construction is in progress, farmers are often forced to endure 1-3 growing seasons with no crops on their land. Further, farmers do not receive money for crops removed before harvest for the construction activities. The amount of funding for recompense is negligible when compared to total project cost, yet it is so crucial to each farm family that has few sources of non-farm income. Failure to recognize this factor makes planning deficient, in the most basic and humanistic sense.

Other settlement problems may arise from irrigation development, such as new housing patterns and disruption of traditional lines of communication. However, these less serious issues can be resolved more easily and with less disruption if the problems of resettlement, land use and land tenure are included in the planning process.

Socio-economic Functions

Implementation of new irrigation systems causes changes in the socio-economic functions of the project area, especially if previous irrigation experience is lacking. Conversion from rain-fed agriculture to irrigation forces farmers to master difficult new methods quickly, which are often quite contrary to traditional practices. Farmer resistence to the adoption of these methods impairs project efficiency and creates unproductive frictions between farmers and project managers. Improved agricultural extension services with demonstration farms can make the conversion less difficult.

Irrigation systems affect existing water use patterns and priorities. Canals and ditches encourage people to use the water for other purposes, including domestic supplies, recreation, or for livestock. The water is unsafe for domestic use and is not suitable for recreation. Livestock use can create hostilities between neighbors over access rights and the larger animals may damage ditch banks. Water used for non-agricultural functions may be diverted to the irrigation project, making it unavailable or less-suited for the other uses.

The amount of energy required for irrigation is an important socio-economic concern. When energy was relatively inexpensive, tractors, mechanized food processors, drying equipment and pumps were often over-sized to provide a margin of safety. Now, with rapidly escalating energy costs, farmers must carry a much heavier burden for the wasted energy or make expensive conversions to more energy-efficient equipment. In new systems, equipment is now sized with a concern for energy, but often at the expense of an adequate safety margin or decreased flexibility.

Lack of labor and available markets have created social problems. In many areas, adequate labor is not available during the labor intensive periods of crop development, especially for planting, weeding and harvest. In other areas, the irrigation projects have diverted labor from other necessary village occupations, such as fishing, woodcutting and home gardening, thereby increasing costs in those areas. Sometimes, local markets have not been developed simultaneously with irrigation adding expensive transportation costs to the farmer's burden.

Although irrigation provides the farmer with a higher probability of a return on his investment, the increased initial expenses require some form of agricultural credit. Without this, he may not have adequate resources for the initial investments for improved seed and agricultural chemicals that are necessary to produce a profitable yield.

In too many irrigation projects, the farmer becomes a victim of the system in which operation costs increase faster than the value of the crops. Management decisions are made by others and, often, prices of the products are fixed by government regulations or agencies which do not exercise control over the operating costs for fertilizers, biocides, machinery and seeds. Without agricultural chemicals, seeds and machinery, the yields from the project will not meet the projections calculated for the benefit/cost studies. To the individual farmer without the agricultural improvements, the value of the crops may be less than the fixed expenses for water, rent, taxes and energy, forcing the family to leave farming to seek better opportunities in the already crowded urban centers.

Obviously, there are other socio-economic functions related to irrigation, many of them site-specific. Given the opportunity, planners will determine which of these functions merit attention, especially if community leaders have been able to participate in project planning.

Social Organization

Successful irrigation demands cooperation and responsible action from many interacting participants. The physical structures - pumps. dams, conduits and distribution mechanisms - may function perfectly, but irrigation will not be effective unless a coordinated sequence of operational and maintenance events occur on schedule Schedules, operation and maintenance involve people; therefore the coordination of these activities demand some type of human organization to accept management responsibility - both central and local coordination, as well as community participation (Yotopoulos 1980). Since irrigation projects are influenced by political decisions and should be part of national water resource planning, the central management is necessary. At the same time, project efficiency is influenced equally by the on-farm management of water and system water delivery, so that a local, decentralized authority has been shown to be extremely beneficial and desirable (Coward 1977).

Problems arise when the social organizations affected by irrigation are ignored during the planning process. Poor communication and coordination between irrigators and system operators eliminate most of the potential benefits by causing disjointed water delivery, mis-timed application and over- or under-application, creating the problems of soil salinity, water logging or reduced yields. The creation of a central irrigation authority to manage the major structures including dams, pumps and supply channels helps to insure the delivery of water when needed. Farmer cooperatives or water-user groups established at local levels to determine schedules, set application rates and maintain the system-to-field structures (ditches, drains, gates or turn-outs) completes the management organization for the irrigation program. Obviously, communication links between operators and farmer-managers must be frequent and effective. In order to achieve an efficient social organization for irrigation, social scientists must aid engineers and agronomists in integrating the project into a comprehensive program which covers the technical, social and environmental aspects of irrigation planning design and operation.

Political decisions at both local and national levels will influence planning and design directions which require social and environmental compromise. For instance, project type and location, crop selection, social organization and project schedules are too commonly determined by politics rather than science. At national levels, a decision to construct a new irrigation system is likely to have more political reward than a project to improve yields at existing agricultural sites through training and other methods, even though new irrigation is far more costly and less effective. The failure to recognize the influence of local political units or leaders can impede or deny the formation of farmer cooperatives or water user associations. Unlike science, politics need not be logical, and political decisions forced on planners may result in faulty irrigation development. Planners must be aware of political implications and allow latitude for compromise in those areas which are not likely to cause severe environmental or social disruption.

Community Participation

Projects which have been planned for people instead of with people have a dismal rate of failure. Many of the social problems associated with irrigation development could have been mitigated or eliminated if planners had sought meaningful community participation. Community support of the project is more likely if local leaders are a part of the planning process. The areas of probable social disruption or popular resistance can be identified by the people most familiar with the social and political fabric of the project area: the local residents.

Community participation and support can be gained through the development of a community profile at the pre-feasibility planning stage. This profile should describe the social, cultural, economic and political aspects of the project area. Local leaders can be identified and urged to participate in the collection of data. An expression of needs and priorities as perceived by the local population must be included in the profile. These can then be used to develop project objectives which would be satisfactory to planners and supported by the community. The most useful community leaders could continue to provide valuable input throughout the planning process.

The various reasons for not encouraging community participation in development projects are numerous, as are the discouraging social impacts created by the projects. Recent evaluations of irrigation projects have demonstrated the importance of community participation in planning at all scales of development (White, 1978, Biswas et al. 1980, Johl 1980, USGAO 1980). The number of international organizations with experience in irrigation planning, funding or operation which now require or recommend community participation in project development is an encouraging indication that community involvement is gaining recognition as a valuable planning tool.

D. Public Health Impacts

It has been said that "wherever water goes, disease follows in its wake." This sad experience of man's development activities occurs nearly every time that man impounds and conveys water for development purposes. The long and unfortunate record of disease increases which are associated with water development in general, and irrigation in particular, demonstrates the increased disease vulnerability of a region following the establishment of irrigation schemes. Despite the knowledge of disease transmission routes, advances in diagnosis, treatment and prophylaxis, and increasing numbers of trained medical personnel, regions near new irrigation sites continue to show alarming increases in disease rates.

Water is a favorable medium for the spread of disease, carrying bacterial and viral pathogens. It is also important in the transmission of parasites, either directly or by providing breeding habitats for disease vectors. (The term vector is used in its broadest sense to represent vectors, animal reservoirs and intermediate hosts). Between 20 and 30 different infective diseases may be affected by changes in water supply, such as irrigation development (Bradley 1977). Often, the diseases are classified by the infective agent, i.e., virus, bacteria, protozoa, or helminthic worm, but this system does little to aid in designing control systems. A more reasonable classification is based on the mode of spread, emphasizing four main categories: water-borne, water-washed, water-based and water-related insect vector (Bradley 1977). Using these categories, irrigation-related diseases can be summarized as in tables V and VI for easy reference to infective agent, mode of transmission and preventive strategy. Tables are from Feachem et al. (1977).

TABLE V

Mechanisms of Disease Transmission

Transmission Mechanism	Preventive Strategy
Water-borne	Improve water quality. Prevent casual use of unimproved sources.

TABLE V (cont.)

Transmission Mechanism	Preventive Strategy
Water-washed	Improve water quality. Improve hygiene. Improve water accessibility.
Water-based	Decrease water contact. Control snails. Improve water quality.
Water-related Insect vector	Improve surface water management. Destroy breeding sites. Decrease human-insect contacts.

TABLE VI

Water-related Diseases and Pathogenic Agent

Category	Disease	Pathogen (vector)
Water-borne	Amoebic dysentary	protozoa
	Ascariasis	helminth
	Bacillary dysentary	bacteria
	Cholera	bacteria
	Diarrhoeal disease	miscellaneous
	Enteroviruses (some)	virus
	Gastroenteritis	miscellaneous
	Infectious hepatitis	virus
	Leptospirosis	spirochaete
	Paratyphoid	bacteria
	Typhoid	bacteria
Water-washed	Conjunctivitis	miscellaneous
	Leprosy	bacteria
	Relapsing fever	spirochaete
	Scabies	miscellaneous
	Trachoma	virus
	Typhus	rickettsiae
	Yaws	spirochaete

continued on next page

TABLE VI (cont.)

Category	Disease	Pathogen (vector)
Water-based	Chlonorchiasis	helminth (snail, fish)
	Diphyllobothriasis	helminth (copepod, fish)
	Fasciolopsiasis	helminth (snail, plant)
	Guinea worm	helminth
	Paragonimiasis	helminth (snail, crab)
	Schistosomiasis	helminth (snail)
Water-related Insect vectors	Arbovirus (some)	virus (mosquito)
	Dengue	virus (mosquito)
	Filariasis	helminth (mosquito)
	Malaria	protozoa (mosquito)
	Onchocerciasis	helminth (blackfly)
	Trypanosomiasis	protozoa (Tsetse fly)
	Yellow fever	virus (mosquito)

Recognizing that irrigation development is vulnerable to significant increases in any of the diseases listed in Table VI, several merit special attention due to their common association with irrigation projects. The diseases are also of special interest because the World Health Organization is developing strategies to combat these diseases in new and old irrigation projects (WHO 1978).

MALARIA

Malaria is one of the most common diseases in the world and it affects over 25 million people (McJunkin 1975). Malaria is a potential threat to any warm region with available water. Caused by parasitic protozoans of the genus Plasmodium, the disease is transmitted by several species of Anopheline mosquitos. A precise description of the life cycles of the malaria parasites is quite complex, involving several stages of development from egg to adult in the vector and differing reproductive stages of the parasite. In simple terms, however, the parasite reproduces in the gut of Anopheline mosquitos, producing infective larvae which migrate to the salivary glands of the insect. When the female mosquito punctures the skin of a vertebrate host to take a blood meal, the larvae are injected into the bloodstream. If the host is appropriate to the development of the parasite, the larvae reproduce asexually in the liver, releasing another asexually-reproducing stage which become encased in red blood cells. At periodic intervals, the bloodstream parasites burst out of the red blood cells to colonize new cells. Eventually this stage ceases to reproduce asexually and develops into a form that must be taken into a mosquito before it can begin the sexual reproductive stage once again. The larvae released from the red blood cells have produced toxins which cause a periodic fever in the vertebrate host, which may be fatal to humans without previous exposure to the malaria parasites (Bradley 1977).

Mosquitos require water for development. Female mosquitos lay eggs on aquatic plants or debris in water bodies. The eggs develop into a larval stage which requires certain types of aquatic environments for further development. Unlike many insect larvae which also develop in water, mosquito larvae must maintain contact with the atmosphere, using special breathing tubes that penetrate the water surface. Thus, larvae development is favored by standing, shallow water; for example, slow-moving irrigation ditches and drains, small pools of standing water or sheltered backwaters. This type of aquatic environment is normally absent, or at least seasonal, in arid or semi-arid regions. When man adds a water development project, such as irrigation, a seasonal and moderate disease may be transformed into a permanent hyperendemic situation (White, 1978). It has been repeatedly noted that irrigation is not particularly harmful if the system is well-planned, carefully operated and maintained to prevent the occurrence of stagnant water in drains, ditches or seepage pools (WHO 1978, White, 1978, Feachem et al. 1977). However, irrigation systems which are characterized by low yields and environmental deterioration are also the ones which contribute to the detrimental conditions for human health. Management actions to improve water use and increase crop yields reduce health hazards at the same time.

SCHISTOSOMIASIS (Bilharzia)

Schistosomiasis is a disease even more closely linked to irrigation development than malaria. Schistosomiasis is caused by trematode worms of the genus *Schistosoma* which are prevalent in 72 countries and islands of Africa, West and Southeast Asia, Latin America and the Caribbean area (WHO 1978). The World Health Organization (1978) estimates that more than 200 million people are infected with one or more of the three main schistosome species: *Schistosoma haematobium*, *S. mansoni* and *S. japonicum*, and more than 600 million people are at risk. The adult worms of *Schistosoma haematobium* inhabit the blood vessels around the bladder, causing urinary schistosomiasis, while the adults of the other two species live in the venous drainage of the intestines, producing intestinal schistosomiasis (Bradley 1977).

Eggs passed in urine or faeces contain a ciliated larva, called a miracidium, which hatches if the egg contacts water. The free-swimming miracidium must contact a suitable snail host within 24 hours or perish (WHO 1978). The intermediate snail host for *S. haematobium* is in the genus *Bulinus* and the snail host for *S. mansoni* is in the genus *Biomphalaria*; both are from the snail family Planorbidae. The genus *Oncomelania* is the most common snail host for *S. japonicum*.

Within the snail, the schistosome migrates to the digestive glands and changes into another larval stage, the cercariae, after about one month. The cercariae leave the snail and swim around seeking to penetrate the skin of a mammalian host, such as man. This swimming stage can survive up to 48 hours between emergence from the snail and penetration of a definitive host (WHO 1978).

In man, the schistosomes enter blood vessels and eventually reach the bladder or intestines (depending on the schistosome species), where they achieve sexual maturity. After mating, the female begins releasing eggs just 30-40 days after penetration (WHO 1978). Eggs escaping into the urine or faeces may cause "transient" damage and blood may appear in the urine or stool. Other eggs may cause nodule formation on the walls of the intestines or bladder, or some may be swept in the venous flow and transported to the liver where they may also form nodules, or granulomas. The worms live for several years, capable of laying hundreds of eggs daily, so damage tends to be insidious and cumulative (Bradley 1977). Since severity is proportional to worm load, the disease tends to be debilitating rather than fatal in most cases.

Public health records from many irrigation projects show increases in morbidity from 2% up to 75% after the introduction of water development projects (Obeng 1977). The snail intermediate hosts proliferate in irrigation drains, ditches and seepage pools. Human contact with water in and near the irrigation system is high, thereby increasing the spread of the disease. Finally, frequent use of irrigation canals for excreta disposal completes the requirements for high schistosome transmission.

Control programs for schistosomiasis have generally been unsuccessful due to a narrow focus of the control method, often relying solely on the use of molluscicides. Several broad spectrum approaches have been outlined, but rarely implemented (WHO 1978, Rosenfield 1978). These comprehensive control programs include habitat modifications to deny snail breeding sites, use of molluscicides for high density snail populations, introduction of snail predators, improved sanitation, safer human-water contacts with dual water systems and disease monitoring and treatment. There is a high degree of optimism for the reduction of schistosomiasis through the use of comprehensive control programs.

FAECAL-ORAL DISEASES

The increase of faecal-oral diseases normally follows the development of irrigation systems, particularly in arid and semi-arid regions. Human populations in these areas tend to be dispersed and the deposition of faeces or urine on remote dry landscapes do not pose serious health threats. When irrigation projects are established the human populations concentrate around the water works and the irrigation structures perform double duties as sources of domestic water and as excreta disposal outlets. This unfortunate combination increases the potential for any of the diseases that are transmitted via the faecal-oral mode. Amoebic and bacillary dysentary, diarrhoeal disease and infectious hepatitis are commonly associated with irrigation. The incidence of cholera and typhoid are much less frequent, but far more serious, often bringing immediate responses from government and international health agencies.

The problem with faecal-oral diseases is compounded by the fact that transmission may also occur through food irrigated with water carrying the pathogens. Unless the contaminated food is thoroughly cleansed or cooked, both of which are unlikely, the pathogens remain viable and capable of producing illness.

Control of these diseases is relatively straightfoward - simply the safe disposal of human excreta and the provision of safe domestic water supplies. But, in a world where 86% of the rural population is without reasonable access to safe water, the simple solution becomes either extremely costly or totally unrealistic. Irrigation development does provide an excellent opportunity to provide sources of safe drinking water and sanitary excreta disposal systems to rural populations. The technical expertise and equipment of irrigation implementation can also be used to eliminate disease, if the improved health objective is integrated into project development at the planning stages.

OTHER INSECT-BORNE DISEASES

Filariasis (mosquito), yellow fever (mosquito) onchocerciasis (blackfly) and sleeping sickness (Tsetse fly) are included in this section. The mosquito-borne diseases are most commonly associated with irrigation for the same reasons given for malaria, primarily poor water management provides excellent breeding habitat for the insect vectors.

Filariasis, or elephantiasis, is caused by a helminthic worm transmitted by a mosquito, most commonly Culex fatigans. This species has extended is range, usually following man's urbanization, because it thrives in polluted waters, such as pit latrines, septic tanks, sullage pits and pools or rivers containing effluent from sewage systems (Laurence 1977). Newly established irrigation centers provide a variety of suitable breeding habitats unless comprehensive mosquito control programs are employed.

Yellow fever and dengue are caused by viruses carried by species of the mosquito genus Aedes. These mosquitoes characteristically breed in small containers of water, such as discarded tins, automobile tires, and coconuts (Laurence 1977). Control of this vector must include clean-up programs, education, mosquito netting for sleeping, supplemented with pesticide applications.

Onchocerciasis is less likely to be a serious factor with irrigation since the blackfly vector breeds in rushing, turbulent water, hardly a characteristic of irrigation systems. Unless the project contains impoundments with turbulent penstocks, onchocerciasis is not likely to be present. In fact, irrigation impoundments tend to reduce blackfly habitats by inundating the rapids of streams and rivers or diverting water flow.

Sleeping sickness can be increased by irrigation in the susceptible zones of Africa. If water channels are lined with dense vegetation, the Tsetse fly vector will find a preferred habitat (White, 1978). Elimination of the vegetation will reduce the incidence of the disease.

OTHER HEALTH IMPACTS

While irrigation projects have been shown to aid in the transmission of numerous pathogens and to increase the populations of disease vectors, several other less-studied health impacts may be associated with irrigation. The conversion from traditional rainfed agriculture to more intensive practices under irrigation calls for significant increases in the use of fertilizers and biocides, both of which may cause adverse health impacts.

Biocides, applied to cropland in order to control agricultural pests and weeds, are available in a wide range of toxicity to animals and exhibit an equally wide range in their degree of persistence in the environment. Many biocides, especially chlorinated hydrocarbons, have been shown to accumulate in animal tissues and undergo biological concentrations in the food chain. This occurs when lower forms of plants and animals, such as algae and arthropods, incorporate the biocides into their tissues in small doses. As these smaller organisms are eaten by larger animals, the small dose in each individual begins to accumulate as the predators devour more individuals. If the larger animals, such as fish and birds, are eaten by still larger animals or man, the toxic concentration increases, accumulating in specific parts of the body, such as the liver or fat tissue. While the dose may still remain at sub-lethal levels, the chronic or long-term effects may pose serious dangers, since many of the biocides may cause cancer, nerve damage or blood disorders over a long period of time.

In some industrial countries, biocide sales and applications are strictly regulated and instructions for safe use are precisely outlined on the container label. In developing countries, sales may not be regulated, instructions are not often in the native language, and medically-untested mixtures may be used by local farmers. Since the side-effects are unknown, only the most detailed study would demonstrate the problems of long-term exposures. At present, the only plausible approach is to assume future dangers and to guard against the excessive use of biocides. Use should be limited to non-persistent and low toxicity chemicals.

High concentrations of fertilizers in water supplies have been shown to cause blood disorders and may cause cancer. In addition, the fertilizers may stimulate excessive algal blooms which can effect the taste and odor of water, rendering it unsuitable for human consumption.

The public health implications of irrigated agriculture are very serious and should be a major part of every irrigation planning effort. While all the adverse side-effects relating to human health cannot be eliminated, proper planning, design and operation of irrigation systems can add a significant degree of control over the major disease hazards.

E. Flora and Fauna

Irrigation projects may have an impact on plants and animals well beyond the area circumscribed by project boundaries. The extent of the impact is dependent upon the amount of site alterations and previous land use. Obviously, native plants and animals are normally excluded from the fields; therefore the projects always remove some habitat for native species. In general, irrigation projects tend to favor the most aggressive plant and animal species, those which often are direct competitors of man. For instance, plants with numerous and highly mobile seeds are able to take advantage of the improved soil moisture and fertility of irrigated fields. High seed output and varied distribution mechanisms are usual characteristics of agricultural weeds. Native plants with reproductive adaptations which depend on the pecularities of arid or semi-arid climates for germination will no longer flourish within the constantly moist fields. This is especially true of endangered species which have very precise habitat requirements. Of course, the endangered species of arid and semi-arid zones are not well known, since botanical surveys of these areas are lacking. However, endemic plant populations, where the entire known world population may be restricted to a few square kilometers, have been studied in several arid regions. It is highly likely that irrigation projects have already pushed some plants into extinction.

In similar fashion, irrigation projects favor animals which are adapted to a broad range of environmental requirements, often considered vermin by man. Animals with high reproductive rates and high mobility will quickly take advantage of the geographically-concentrated, bountiful yield of an irrigated field. Insects, rodents and some birds can be characterized by these qualtities. In fact, in many areas the most serious threat to agricultural productivity is not related to soil moisture, fertility or climate, but to losses from agricultural pests. It is not uncommon for developing areas to have crop and storage losses of over 50% due to insects, rodents and birds. The problem is exacerbated by irrigation practices that reduce natural predators of agricultural pests. Complete removal of native vegetation surrounding irrigation fields eliminates cover and habitat for larger predators, such as snakes and birds, which prey upon insects, rodents and seed-eating birds. And finally, poison for rodents and birds may eliminate predators as well as the vermin, ensuring a continued reliance on expensive poisons. Rarely do agricultural schemes, irrigated or rain-fed, seek to exploit the contribution of natural predators by providing habitat requirements for their existence.

In aquatic ecosystems, irrigation may have several adverse effects. If parts of water courses are diverted for irrigation, the reduction of downstream flows has several adverse effects on the flora and fauna. Not only are the wastes and toxins more concentrated, but the water carries less oxygen, so that the added organic wastes increase the biochemical oxygen demand to the point that all available oxygen is used for decomposition and none is left to support aquatic animals.

At the same time, run-off from irrigated fields compromises water quality with salts and toxic chemicals. Water temperature increases from irrigation drains, coupled with the chemical additives, change downstream habitats, usually favoring the most tolerant, least desirable species.

Proliferation of algae and waterweeds caused by elevated water temperatures and increased nutrient loads from fertilizers further reduce water velocities and increase oxygen demand by eliminating sub-surface plants that depend on light penetration through the water column for their existence. Stagnation of surface water eliminates many valuable animal species which require oxygenated, free-flowing water, including sport and commercial fish and aquatic mammals. Important spawning areas may be eliminated by reduced flow, chemical additives or sedimentation as a result of erosion.

Irrigation projects may affect rare or endangered species. Since most of the rare species have specific habitat requirements or intolerance to pollution, extensive environmental modifications usually work against their well-being. The effects on endangered species are difficult to measure or predict since the low population numbers and inadequate inventories are unlikely to identify either endangered species or their habitats. Superficial surveys are not likely to define behavior patterns or habitat requirements of rare species, if they are even encountered at all. Impacts on endangered species will continue to be an unknown factor until populations and the biology of the species have been more fully detailed through international research efforts.

The non-human environmental impacts of irrigated agriculture discussed in this section present an extensive array of potential problems. Unfortunately, examples for each instance can be cited from every continent using irrigation. The repeated cycle of irrigation development and subsequent adverse environmental impacts underscores the need for environmental analysis for irrigation organized in systematic steps for project appraisors and evaluators. While all of the complex relationships of irrigated agriculture cannot be understood, nor all effects predicted in advance, the probability of minimal impacts can be increased by adequate knowledge of the ecosystem prior to planning and design. A multi-disciplinary approach can be effective only if such data are assembled for evaluation and worked into the planning process. The number of irrigation projects that proceed from concept to operation without adequate preliminary studies is alarming, expecially in a technological age which places value on data collection and interpretation. To continue irrigation development without benefit of environmental analysis, as in the past, is counter-productive at best, and environmentally dangerous at worst. If the world is to survive the food crisis, it must not allow disease, soil deterioration, social disruption and water degradation to offset the obvious benefits of irrigated agriculture.

V. ENVIRONMENTAL ASSESSMENT GUIDELINES FOR IRRIGATION

RATIONALE

Environmental assessment is a process involving the systematic collection and interpretation of data. For optimum results, data must be adequate, reliable and organized. If environmental data are collected and organized in a systematic way, the adequacy and reliability are improved and are more easily evaluated. The preparation of an environmental data checklist is the recommended format to guide data collection and analysis. Consider the analogy of an airline pilot's pre-flight checklist. In spite of extensive experience in the airplane, pilots still proceed through a pre-defined checklist to gather instrument data on the aircraft's operating condition. In the same fashion, an environment assessor proceeds through an irrigation data checklist to gather information on the various factors which relate to the operating condition of a proposed or existing irrigation system. Continuing the analogy further, the use of a checklist does not guarantee success, but acts to reduce the probability of failure or unanticipated events.

As with the environmental scientists, the airline pilot is not required to have complete understanding of all the different factors which contribute to successful take-off and operation, but merely an ability to recognize certain danger signals during the pre-operation procedures. Experts in various disciplines, such as electronic technicians or mechanics for the pilot and geologists or agronomists for the environmental scientist, can be called in to interpret unusual data or to evaluate and remedy potential malfunctions. Operation of a sophisticated jet aircraft is a complex task, requiring a multi-disciplinary team to accomplish the objective. It has been demonstrated in previous sections that planning and operating a successful irrigation system is an equally complex undertaking. The checklists are merely one small and vital part in the operation, but not one to be ignored.

A model environmental data checklist is offered in Appendix I. It is designed to accommodate medium- to large-scale irrigation projects.

For convenience, the following guidelines and the environmental data checklist are divided into four planning and operational categories:

- Proposal or pre-feasibility;
- Planning and design;
- Implementation (construction);
- Operation and maintenance.

A. GUIDELINES FOR PROPOSAL OR PRE-FEASIBILITY STAGE

COLLECT AND ORGANIZE ENVIRONMENTAL DATA INTO A CHECKLIST FORM.

The literature on environmental assessment contains many methods for collecting, organizing and analyzing environmental data. Most of the methods assume that data are complete and are at hand. This is not usually the case for irrigation projects proposed for developing countries, so that matrices and scaling techniques are not applicable. A checklist, a rather simple format, organizes data in a form that illuminates deficiencies and reduces the possibility of oversight. Further, the checklist can be used to structure data for easy access by technical consultants.

DO NOT SUMMARILY REJECT ENVIRONMENTAL DATA CHECKLISTS.

An initial reaction to checklists, such as the example in Appendix I, may be rejection, the arguments for which will be persuasive and follow one or more categories:

a. The checklist is too long and requires more data than are necessary. It will be said that successful irrigation projects have been planned and implemented with far less planning information. The occurrence of irrigation projects that increase disease, accelerate soil and water degradation and fall short of projected yields should indicate the shortcomings of irrigation planning without adequate data. The checklists may be long, representative of comprehensive planning. The degree that information sets are lacking is proportional to the probability of making a planning error.

b. The checklist is too complex. Irrigation is the most complex land management experience known to man. Successful planning and design require close cooperation and technical skills of a multi-disciplinary team with expertise in engineering, soil and water science, agronomy, meteorology, public health, economics, social science and environmental science. The degree of technical input from each discipline varies with the stage of development. However, for efficiency, the data should be arranged so that experts in each discipline can raise pertinent issues for discussion with experts in other fields, or request interpretation of data. Further, when outside expert consultation is required, the data are organized for immediate review, reducing time spent searching for data.

c. It is unrealistic to expect to find the required information in a developing country. The primary problem of data collection in these countries is not so much a factor of the existence of material, but one of location. The most extensive environmental data are often found in the headquarters of international organizations, such as Washington, Paris, Rome or Geneva, rather than in the country of origin. The international agencies conduct studies on soils, weather, water, flora and fauna, public health and agriculture, but either do not leave copies of the reports for the host countries, or the copies are misplaced. Developing nations do not have the financial resources to keep pace with the advances in information storage and retrieval. Certain agencies within the national governments may have project area data or maps, quite unknown to other government agencies. The effort spent on preliminary data collection is well worth the time, if environmental assessment at the proposal stage is intended to be something beyond rubber stamp approval. Even when politics or other pressures assure proposal funding, the accumulated data are still of vital importance to the planners.

Where important data sets or maps are lacking, the funding agency receiving the proposal should consider making the investment to collect the data or prepare the map before considering the proposal further.

CONSIDER IRRIGATION IMPROVEMENT ON EXISTING PROJECTS AS AN ALTERNATIVE PROPOSAL.

Before assembling data for new irrigation projects, existing projects should be evaluated as potential candidates for improvement. International organizations studying global irrigation consistently favor the improvement or rejuvenation of existing irrigation sites as the most cost-effective alternative for increasing food and fiber production. Dramatic advances in irrigation technology in the past two decades provide excellent opportunities to upgrade systems currently in operation. The improved technology has increased agricultural production, decreased health hazards and conserved water in many areas of the world.

The advantages of irrigation improvement versus new projects are:

- Lower capital costs per unit of production;
- Existing data on project area;
- Farmers have experience with irrigation;
- Potential problems more readily identified;
- Less social disruption.

While these are compelling arguments for irrigation improvement, planners and politicians have a preoccupation with high visibility, new capital works as opposed to the less dramatic, but more cost-effective improvement projects. In some cases, this reluctance to promote improvement proposals is based on the false assumption that if systems can be improved, the initial project design was at fault. Such is not the case, since much of the increase in efficiency will result from technology or research which was not available during initial design. In addition, recent management studies have demonstrated that improved yields can result from different operational and maintenance techniques. Funding agencies should routinely insist on higher priorities for project enhancement than for new development, unless extenuating circumstances preclude that option.

DETERMINE HOW THE PROPOSED PROJECT RELATES TO NATIONAL GOALS AND PRIORITIES.

In most countries, the allocation of national resources must be done with care. Development goals and priorities are often defined in national policy statements or in long-range plans for specific development sectors, such as water, agriculture or public health. The environmental scientist must understand that factors other than environmental protection are used to determine the objectives and priorities of development, such as self-sufficiency in food, improved balance of trade, land reform or political stability.

The proposed project will relate to one or more of the defined objectives. This relationship may be positive to some and negative to others. Therein, the planning process becomes a series of compromises and evaluations of priorities. As long as the objectives are not self-serving to only a small group of individuals, there will be no "right" solutions which will satisfy all development sectors. For instance, water allocated to agriculture may no longer be suitable for domestic use or tourism, or the decision to grow cash crops for export will improve the balance of trade to the detriment of a program for food self-sufficiency.

By relating the proposal to national objectives, the environmental scientist will be more aware of which decisions may be determined by political, social or cultural factors, rather than by environmental conditions. In these cases, environmental arguments or compromises must be tailored to relate to the national goals and/or priorities, and not given as pleas for environmental quality or threats of impending ecological disaster.

LOCATE PROJECT AREA ON LARGE-SCALE NATIONAL OR REGIONAL MAPS.

This preliminary step permits assessment of distance-related project effects. Important considerations are the distance to the nearest urban center, seaport or navigable river, international border, planned or existing national parks or reserves, upstream industrial sites and downstream urban areas, among others. A project which is remote from urban centers, seaports or navigable rivers will have increased construction costs due to expensive overland transportation. The higher transportation costs will also affect market values of the agricultural products after the project is completed. Further, cities are the major source of skilled labor for construction and maintenance. A remote project location may delay construction and cause difficulties in securing the necessary materials for agriculture (machine parts, seeds, fertilizer and biocides). Health and extension services are less likely to be available to remote areas.

Proximity of irrigation projects to international borders or protected natural areas have caused environmental problems. International tensions have increased over the issue of water rights, reduced water quality and increased migration across national borders for employment or commerce. Natural areas have been compromised by encroachment resulting from higher population densities in the vicinity of irrigation development. Other irrigation-related influences on natural areas or parks include the effect of return flows on fish, concentration of agricultural pests or changes in the migratory patterns of wildlife. In some cases, larger wildlife species come in serious conflict with farming interests, destroying crops or irrigation structures on a regular basis.

Since irrigation projects can be impacted by upstream water use (industrial effluents, other irrigation) potential upstream development must be considered in planning. Downstream effects of the project can also be serious, although diversion and water quality changes sometimes become attenuated over distance; therefore the distance between the irrigation site and downstream water users is an important planning parameter.

DETERMINE ACCESSIBILITY OF PROJECT AREA.

Maps or air photos can be used to evaluate accessibility. Roads, railroads or navigable rivers should be identified, as they are directly related to economic, social and environmental factors. In many cases, the ease of access changes seasonally due to differences in river flows or road conditions. Ease and time of project area access must be factored into harvest and marketing strategies.

DETERMINE EXISTING LAND USE PATTERNS.

The value of current air photography of the project area cannot be over-emphasized. Stereo-pair aerial photography can be used to prepare base maps for soils, geology, surface water, drainage patterns as well as current land use.

- Potential land use conflicts: e.g., unfenced rangeland, probably used for livestock grazing, may be at odds with irrigated agriculture.

- Social factors: e.g., villages within the irrigated perimeter might require resettlement plans.

- Education considerations: e.g., lack of irrigation within the region indicates a need for agricultural extension programs.

- Public health: e.g., poorly drained areas are potential habitats for disease vectors.

- Flora and fauna: e.g., tracts of natural vegetation may need to be removed for cropland.

- Agricultural: e.g., small individual holdings not compatible with efficient irrigation and may require land consolidation.

This list is not inclusive. There are many more areas which require consideration and can be studied in part through interpretation of aerial photography. However, even the most skillful use of air photos will not eliminate the need for site visits and surveys for verification or refinement of data, but the amount of field time can be significantly reduced and field visits can be better organized.

ORGANIZE GEOLOGICAL DATA INCLUDING AVAILABLE SOIL INFORMATION.

Accurate soils information is of paramount importance in the planning and design of irrigation projects and should be one of the first topics for field surveys. At the proposal stage, soil data are likely to be general and sparse. For environmental assessment purposes, it is better if the available soil information can be arranged by soil scientists into irrigation suitability maps. By using criteria established by the U.S. Department of Agriculture and the Food and Agricultural Organization of the United Nations, technical data on slope, texture, structure, permeability and chemistry can be used to map the soils in the project area as to their suitability for different irrigation methods. These maps, subject to revision with additional data, can also be used to identify the types of problems which may occur if mitigative steps are not taken.

ORGANIZE CLIMATOLOGICAL DATA INTO MORE USEFUL FORMS.

Climatological data are also likely to be sparse at the proposal stage, as developing countries have few long-term reporting meteorological stations. Organizing the available information will provide a measure of reliability for the data. Because of the temporal and geographic variability of climate characteristics of arid and semi-arid regions, data taken from off-site stations over short time frames are likely to be highly unreliable. Meteorological stations should be established at the proposed project site as quickly as possible. Agronomists will require on-site data to calculate crop water requirements which will influence irrigation design, crop selection and crop rotations.

ORGANIZE WATER INFORMATION.

Since water supply in arid and semi-arid regions is a limiting factor in other development areas, such as power generation and industry, governments in these regions tend to allocate more resources to water studies and planning. The amount of information on water supplies is usually greater than information on soils and climate. However, water quality does not receive the same level of attention as water supply, so it may be necessary to program supplemental water quality studies. As with soils, scientists using international criteria can rate different water supplies with regard to their suitability for irrigation. Water which is suitable for industrial or domestic use may create problems, such as salinization or alkalization, if used for irrigation without appropriate water management techniques. If surface waters are proposed for irrigation, it is vital to know the amount of suspended materials present, as these particles clog irrigation structures and reduce storage volumes in surface reservoirs unless control measures are taken.

EVALUATE THE AGRICULTURAL PRACTICES IN THE PROJECT AREA.

The ultimate success of any irrigation project is determined by the person who must apply water to the field. An experienced irrigator can compensate for many imperfect conditions, but the best system cannot compensate for an inexperienced irrigator. In order to achieve maximum benefits of irrigation, farmers must accept the concept of irrigated agriculture and be aware of the techniques most appropriate for the farming situation.

If these are not common to the country or region, it will be necessary to plan an active community participation program, plus developing agricultural extension services to provide training to farmers. Resistance should be expected, since many farmers do not consider farming merely an occupation, but a traditional way of life. Plans for demonstration plots prior to project implementation will give the farmer more time and evidence for consideration.

EVALUATE THE AGRICULTURAL ASPECTS OF THE PROPOSED PROJECT.

Frequently, proposed crops, rotations and irrigation methods are established in advance of detailed evaluations of soils, water and climate. Modifying the environment to accommodate a predetermined crop or irrigation method is far more difficult than to modify the selection of crops, rotations or irrigation techniques to the environment. Crop selection and irrigation method should be reserved as options until later planning stages when the detailed environmental data are available. A wide assortment of alternative combinations is possible for implementation in respect to soil, water, climate and market potential. Unfortunately, tradition, national economic and political considerations can have more influence than science and an inappropriate crop or irrigation method might be chosen over more environmentally sound options. It is up to the planners to design the best compromise.

Other potential benefits should be explored at this stage; for example, fish culture is commonly practiced with irrigation with excellent results. Impoundments, supply canals or paddies may be used to raise fish. In addition, fish may be used to control weeds and disease vectors in the water supply systems.

Preliminary assessments of agricultural chemical use can be made. Irrigation normally increases the use of fertilizers and biocides. Whether the chemicals will cause problems will depend on availability, amount applied and the rate and fate of irrigation return flows.

ORGANIZE THE PRELIMINARY PUBLIC HEALTH DATA.

At the proposal stage, existing public health data are usually sufficient for general assessment of the potential health impacts of the project. Normally, information can be found on the types of diseases, extent of health services and community health profiles for the project area. Field visits provide necessary information on the domestic water supplies and the methods for excreta disposal. From experience with other irrigation projects in similar environments, public health planners can identify potential health hazards. Fortunately, disease levels can be mitigated through project design and operation factors, if control programs are developed during early planning stages. At the proposal stage, the main objective is to identify areas of concern which merit additional study during later development stages.

EVALUATE EXISTING INFORMATION ON BIOTIC COMMUNITIES.

There are very few regions of the world that have not experienced some type of scientific investigation by zoos, museums, botanic gardens or gentlemen explorers. The published reports of these expeditions are more likely to be found in foreign libraries or scientific institutions than in local collections. Fortunately, modern information retrieval systems and duplication services can make these valuable references available in a relatively short time if the investigators have access to a modern library system. These accounts of the scientific expeditions, regardless of the publication date, contain important ecological indicators of the project area.

Another important exercise is to list the endangered species which may use the project area. Range maps, migratory routes and background information on all endangered species are available through the International Union for the Conservation of Nature and Natural Resources (IUCN) in Gland, Switzerland. In certain cases, the IUCN will provide technical advice or assistance in developing plans or surveys for wildlife populations.

Visits to local markets within the proposed project area are valuable sources of information. At the markets, one can get an idea as to the types and volume of plant and animal products, including fish, used by the local population. At remote locations, it is often possible to find parts of endangered species (ivory, teeth, pelts) offered for sale at the markets.

The extent of natural or semi-natural vegetation should be mapped. The scientific and ecologic value of natural ecosystems has been well established and these areas should receive protective consideration, if at all possible, within the planning framework.

COLLECT AND ORGANIZE PRELIMINARY SOCIAL AND ECONOMIC DATA.

A common flaw in irrigation planning continues to be a lack of understanding of the importance of people, the supposed beneficiaries of project implementation. An understanding of the social and cultural factors is more vital to project planning than any other environmental component. It may be less difficult for irrigation engineers and agronomists to modify irrigation systems and cropping patterns to suit environmental requirements than it is for social scientists to gain community acceptance and support of the project. In most cases, successful irrigation occurs only when social planning is in step with non-human aspects of development planning.

Much of the social and economic data can be taken from the land maps, air photos and public health surveys. However, additional information is required to complete the pre-feasibility human environment survey.

Irrigation projects always cause land tenure changes because land is required for impoundments, structures and roads. In some cases, human settlements are involved and in other cases, agricultural land is taken. A common circumstance of irrigation is land consolidation for ease in irrigation or maintenance. Farm field boundaries are changed for more efficient management of water and machinery. Plans for land re-allocation or resettlement are difficult and result in extensive social disruption. Assessment at this planning stage should identify the extent of resettlement and land consolidation which will result from project implementation. Fortunately, the increased yields from irrigated agriculture allow farmers to cultivate less cropland, but they must be fully aware of this benefit at early planning stages.

If data are not available on the local economy, the field visits can produce a narrative description that will suffice for early planning stages. Precise figures of per capita income are not necessary, but knowledge of the general level is valuable. It is necessary to know the type of markets and commerce present. Strict barter systems will work against irrigation projects, since farmers must receive cash to pay for seeds and agricultural chemicals, unless a central agency or farmer cooperative is established to act as an exchange agent for the farmers.

Project planners should work closely with community leaders to gain support for the project. Both formal and informal patterns of leadership and local decision-making should be studied to identify the most influential people in the project area. In fact, these local leaders can contribute valuable suggestions for the project.

Nomadic herdsmen are a common feature of arid and semi-arid regions. Their migrations take advantage of seasonal water and forage. Irrigation projects are often at odds with the herdsmen, since projects are often located at traditional stopping points or bar the usual route of the herds. This can cause serious repercussions, both with the herdsmen and the irrigators. Projects must be designed to accommodate both groups.

Other non-agricultural uses of the natural resources should be defined. Irrigation could affect local fisheries, hunting, wood gathering and tourism. Although tourism is not well established in many regions of developing countries, the potential is great. Project planners should assess the prospects for increased tourism and the impacts of the project. In most cases, the impacts of irrigated agriculture on tourism are unfavorable unless wildlife is preserved, archaeological sites protected or an area of scenic value is enhanced by well-managed farmland. Large reservoirs, designed and managed for multiple use, often increase tourism or recreational values.

MAKE PRE-FEASIBILITY ASSESSMENTS AND RECOMMENDATIONS.

The primary tasks in environmental assessment at the proposal stage are to identify potential problems that must be considered in future development stages. Given further study, some of the potential problems may be shown to be less serious and other problems can be solved by design modifications, training or control programs. However, where human welfare is the central issue, it is better to err by identifying problems that may not materialize, than to overlook an impact that could have been corrected.

Project proposals are not likely to be rejected at this stage for purely environmental reasons. The data are just not sufficient to predict severe impacts with a high degree of certainty. However, if the economic feasibility and the agricultural benefits are marginal, a project with potentially serious environmental impacts should not receive additional consideration.

Since planning and design stages are costly, involving detailed engineering, environmental and social analyses, assessment of the proposal should not be routinely approved if serious deficiences are present. Once time and funds are invested in project planning, a tendency to continue develops. Agencies and governments are reluctant to commit funds to planning and later to abandon the project. It is far easier to halt an unwise project at the proposal stage.

B. PLANNING AND DESIGN

CONTINUE TO USE ENVIRONMENTAL DATA CHECKLISTS AS PLANNING GUIDES.

The responsibility of environmental assessment shifts from identifying potential impacts to evaluating techniques or structures which will reduce the environmental effects of project implementation. Potential impacts identified in the proposal stage should be considered in joint meetings between the various planning disciplines. This prevents one problem from being solved while creating another. Guidelines at this stage focus on irrigation techniques, structures and planning strategies which have proved effective in other irrigation projects.

EMPHASIZE THE IMPORTANCE OF ADEQUATE DRAINAGE.

Soil scientists and irrigation engineers understand the importance of drainage in irrigation and will prepare designs for effective systems. This design must receive the strong support of all other disciplines. Inadequate drainage has been found to be a major factor in many irrigation problems, expecially soil salinization, water logging and health. Well-designed drainage systems are sometimes eliminated or reduced in scope between the planning stage and actual construction, often for reasons of economy. In one case, decision-makers postponed construction of the drains because of limited funds. The project soils quickly became salinized and a more expensive drainage system had to be built to reduce the soil salt concentrations. In the interim, farmers had to suffer crop losses and further disruptions. Strong support for the drainage design at all development stages will emphasize the necessity of this vital irrigation feature.

CONSIDER LINED OR CLOSED CONDUIT WATER CONVEYANCE SYSTEMS.

Lined canals or piped systems are more expensive than unlined structures, but provide multiple benefits. Water conservation is enhanced, soils are more easily managed and health hazards are reduced. Certain factors, such as permeable soils, high evaporation rates, or endemism of schistosomiasis and malaria, increase the environmental benefits of lined or closed conduits. If economics preclude linings or pipes for the enitire system, priority areas should be selected for the treatment. These areas would include zones with highly permeable soils or loci for desease vectors.

INSIST ON EFFICIENT CONTROLLED TURN-OUTS FOR SURFACE IRRIGATION SYSTEMS.

Systems without controlled turn-outs are wasteful of water, contribute to erosion and create pools of standing water for snail and insect breeding. These systems supply water to irrigation ditches through continuous flow pipes or gates, or over farmer-dug depressions in the ditch bank. Water volume is difficult to control, leading to over-irrigation and increased bank seepage between irrigations. Low-cost wood, metal or concrete turn-outs have been designed for systems in developing countries and have been used successfully to upgrade existing systems.

CONSIDER THE FOLLOWING STEPS FOR IMPOUNDMENT PLANNING (If applicable).

- Plan removal of all vegetation which would emerge at maximum draw-down to aid in fishing, navigation and reduce vector habitat.
- Plan clearance of all vegetation in zone of water fluctuation for access, vector control and fishing.
- Design for straightening of shoreline by cutting, dikes, filling and deepening for mosquito control.
- Plan to drain all marginal depressions toward reservoir for vector control.
- Plan for multi-level discharge points for mixing impoundment water.
- Explore potential for periodic fluctuation of impoundment water level for vector control.
- Plan for access to impoundment for vegetation management and vector control programs.
- Design screened intakes or deep intakes to prevent passage of snails into the canal system.
- Plan for physical barriers between human settlements and impoundments to discourage human use.
- Assess need for fish ladders in impoundment structure for migrating fish.

CONSIDER THE FOLLOWING STEPS FOR CANAL PLANNING.

- Design canals for straight lines or with bends of ample curvature to prevent backwaters or slow moving water.
- Plan for access to canals for vegetation management, removal of sediments and vector control.
- Plan for gates at lower end of canals so they may be flushed empty to nearest drain.
- Design appropriate wildlife, livestock and human crossings.
- Plan for filling or draining borrow-pits along canals and roads.
- Plan for protective devices against scouring that may form depressions at culverts, drops, chutes or control structures, and make provisions for repair when the depressions occur.

BE AVAILABLE TO ASSIST IN JOINT PLANNING WITH OTHER DISCIPLINES.

- Agronomists - social scientists preparing plans for agricultural extension and demonstration farms.
- Public health specialists - irrigation engineers for water management programs and structure design to reduce habitat for disease vectors.
- Agronomists - biologists to prepare integrated pest management plans.
- Irrigation engineers - biologists to plan and design methods to protect selected biotic communities.
- Soil scientists - agronomists - water scientists to evaluate water quality of return flows and their impact on downstream environments or groundwater.
- Engineers - public health specialists - social scientists to plan and design domestic water systems and human excreta disposal methods.

REVIEW BIOTIC COMMUNITY SURVEYS.

- Evaluate the potential for the presence of endangered species.
- Prepare data of relative abundance for plant and animal species.
- Assess the need for reforestation or afforestation programs.
- Identify the extent of human use of natural biotic communities.
- Assess the potential for fish culture or aquaculture in canals, basins or impoundments.
- Assess the potential for biological control of agricultural pests, disease vectors and waterweeds.

PREPARE REPORT ON RECOMMENDATIONS.

Each mitigation feature has an implementation expense which must be compared against the potential benefits. The decision to follow any or all recommendations may be decided on a strict economic basis or with supplemental social aspects. There is an increasing trend toward weighting social factors when considering benefit/cost decisions. Regardless of the funding criteria, design options will be judged on cost-effectiveness, therefore environmental recommendations should be reported with priorities or benefit/cost analyses to aid the decision-makers. The difficulty with many environmental or social recommendations is to evaluate a quantifiable cost against an unquantifiable benefit. Therein lies the need for adequate explanation of the benefits or value of the planning recommendations.

C. IMPLEMENTATION

CONTINUE ENVIRONMENTAL INPUT DURING CONSTRUCTION.

A recurring tragedy of development is that environmental considerations cease at the planning or assessment stage. Detailed plans are of little value if contractors are free to ignore recommendations or do not adhere to specifications. Projects are rarely evaluated during or after construction, except in regards to structural integrity or economics, which are supervised by construction engineers or economists. The same regard is not given to environmental or social factors, unless some serious post-construction effect or impact appears. By then, the contractors and engineers have left the project area and are not available for remedial actions. It is a mystery why so much attention is devoted to planning and so little effort is given to supervision during construction, even in the developed countries. Environmental supervision of construction activities is sadly lacking throughout the world.

DISCUSS IMPORTANCE OF ENVIRONMENTAL RECOMMENDATIONS WITH CONSTRUCTION SUPERVISORS.

Unless someone makes an effort to point out the importance of the environmental features of the project plan, the contractors may not realize the true value of the recommendations. Periodic reinforcement of the environmental aspects helps to assure contractor compliance, or better, support.

BE AVAILABLE TO ASSIST WITH MONITORING AND TRAINING PROGRAMS.

For the most part, specific monitoring and training programs will be under the direction of specific agencies. However, most, if not all, will profit from environmental assistance. At the same time, the specialists will recognize values in environmental preservation and will strengthen this part of their training programs.

D. OPERATION AND MAINTENANCE

EVALUATE EFFECTIVENESS OF ASSESSMENT AND PLANNING.

Post-construction evaluation is surprisingly uncommon, with little inquiry as to whether environmental assessments were accurate or if the planning procedure was effective. Post-construction evaluations would provide excellent feedback for planners, if experience is considered to be a valuable guide. Berry (1980) provides a detailed analysis of the methods and values of post-construction evaluation of irrigation development. He recommends an evaluation design based on five components.

- Economic viability;
- Efficiency in resource use;
- Effectiveness of water delivery systems;
- Environmental quality;
- Social soundness

The evaluation criteria for these five categories are especially useful. Since the Berry report is not widely circulated, the criteria are reproduced here.

Economic viability

An irrigation scheme should contribute significantly to agricultural output. Qualitatively and quantitatively, how does the project contribute to the household, local and national economics? How does its performance square with the projections?

1. On farm:
    - levels of output achieved;
    - levels of output projected;
    - pattern or composition of cropping.
2. Project-wide:
    - pre-project benefit/cost ratio achieved;
    - projected and realized output;
    - impact of project itself.
3. National:
    - impact on national food budget;
    - contribution to gross national product;
    - influence on foreign exchange;
    - economic impact on non-project areas in country.

Resource use

An irrigation project represents a significant commitment of resources - both nationally and internationally. How are the following resources employed? Does the project represent the optimal use of those resources? What are the relevant opportunity costs?

1. Land:
   - land use;
   - cropping patterns;
   - alternative sites or new sites opened;
   - alternative uses of land because of irrigation;
   - alternative methodologies or patterns of resource uses.
2. Water:
   - volume used;
   - source;
   - alternative uses;
   - alternative sources.
3. Capital inputs:
   - use of capital inputs;
   - initial investment of funds;
   - machinery and fertilizer inputs;
   - credit availability and use;
   - payment for water;
   - financial viability of the system.
4. Labor:
   - employment data, emphasis on seasonality;
   - source of labor

Water system

With each irrigation project, a physical system for the delivery of water to farmers is designed and built. How well is it built and does it function as intended?

1. Performance:
   - construction abides by plan;
   - design efficiency;
   - water promised and water delivered;
   - excess water adequately drained.
2. Management decisions:
   - maintenance;
   - rotation;

- conflict resolution;
- local input;
- adaptability and related organizational considerations.

3. Appropriateness of system:

   - suitability of system to local social conditions;
   - environmental conditions;
   - proper maintenance by local efforts.

Environmental quality

Irrigation projects are artificial means of applying water to land. Thus, they represent a technologically-induced environmental change, and what becomes of the newly-created or destroyed ecological niches?

1. Health:

   - existing disease patterns;
   - changes in disease patterns;
   - increase of water-borne diseases;
   - change in sanitation situation;
   - nutrition, especially of children.

2. Soils:

   - types of soil;
   - increased fertility;
   - negative complications, such as increased erosion, salinization, alkalinization, etc.

3. Pests:

   - existing pests and weeds;
   - new pests and weeds;
   - types and effects of pest control used.

4. Fertilizer:

   - previous fertilizer used;
   - impact on crops themselves;
   - side-effects in streams, run-off and project area.

Social soundness

Any irrigation system must be used by people. What is the society like that uses the system? How does society change because of the project?

1. Pattern of production:

   - indigenous mode;
   - induced shifts;
   - group relations;
   - newly emergent class.

2. Social unit:

   - indigenous household unit;
   - changes in that unit and its function;
   - changes affecting primarily one portion of
   - that unit.

3. Cultural integrity:

   - traditional patterns;
   - changes;
   - loss of skills/knowledge.

4. Wealth distribution:

   - shifts in income or land ownership;
   - changes in pattern of income or land ownership;
   - class polarization;
   - poor farmers helped;
   - risk minimized for small farmers.

5. Management decisions:

   - changing framework for decisions;
   - change in local control;
   - effects of shifting decision base.

6. Role of women:

   - status enhanced or decreased due to project;
   - family viability change;
   - shifts in responsibility related to food production, marketing, household management, etc.

This brief, but excellent, evaluation format underscores the need for complete data collection at the proposal stage. Project evaluation in the suggested categories is not possible without initial baseline survey work. The results of this evaluation certainly will improve project planning and validates its role in the preservation or enhancement of environmental quality and social well-being.

IDENTIFY OPERATION AND MAINTENANCE DEFICIENCIES.

Even well-designed and properly constructed irrigation projects fail to achieve objectives or create adverse environmental and social impacts if the system operation and maintenance are sub-standard. Based on the experiences gained during the preparation of the guidelines, the least productive irrigation projects demonstrated a recurring set of characteristics which indicate poor operation and management. In some cases, the characteristics appeared singly, while in others multiples were common, revealing serious flaws which will likely force project abandonment if operation and maintenance does not improve. The following characteristics of an operating irrigation system provides visual clues to poor irrigation operation and/or maintenance:

- standing water in ditches, drains, non-paddy cropland, borrow pits or adjacent non-agricultural land;
- weed or sediment-choked ditches or drains;
- excessive seepage from turn-outs or canal banks;
- white crusts at cropland surface;
- non-functioning pumps;
- abandoned ditches or canals;
- depressions at turn-outs, outfalls, or water control structures;
- absence of water monitoring devices;
- uneven pattern of crop growth in same field;
- abandoned fields;
- canals used for domestic water or recreation;
- bank erosion caused by livestock bathing.

The list is not inclusive, but a poorly operated or maintained system will show one or more of the characteristics listed above. Better planning and training would eliminate most of operation and maintenance deficiencies.

VI SUMMARY

The interacting social and environmental variables of irrigation planning, design and implementation present a serious and complex challenge for development planners. The potential benefits derived from irrigation are enticing objectives economically, socially and environmentally. Unfortunately, expected benefits have been too often negated by unexpected and very costly social or environmental disruptions.

The extensive general literature on irrigation and the various convocation of international experts have shown that hindsight is nearly perfect, capable of identifying problems after they have occurred. What is obviously needed is to improve foresight; identifying and remediating problems before they occur. Comprehensive and integrated multi-disciplinary planning for irrigation projects is the recommended approach to maximizing irrigation benefits, while eliminating or reducing negative social and environmental impacts.

The guidelines and environmental checklist provide a format for irrigation development planning in general, subject to modifications for site-specific applications. Neither the guidelines, nor the checklist is offered as being complete, but only as a comprehensive beginning for environmental assessors. Users that find deficiencies or limitations in the coverage will have already achieved the objective for guideline development: improved foresight and better irrigation planning and design.

VII REFERENCES CITED

Ackermann, W.C.; White, G.F.; Worthington, E.B. 1973. *Man-made lakes: their problems and environmental effects.* Am. Geophysical Union, Washington.

Adler, J.; Cook, W.; McGuire, S.; Lubenow, G.; Kasindorf, M.; Maier, F.; Morris, H. 1981. The browning of America. *Newsweek*, Feb. 23, 1981, pp. 26-37.

Ayers, R.S.; Westcot, D.W. 1976. *Water quality for agriculture.* Irrigation and Drainage Paper #29. Food and Agricultural Organization of the United Nations, Rome.

Bernstein, Leon. 1964. *Salt tolerance of plants.* Agriculture Inf. Bull. #283, U.S. Department of Agriculture, Washington.

Berry, Leonard. 1980. *The impact of irrigation on development: issues for a comprehensive evaluation study.* Discussion paper prepared for the U.S. Agency for International Development. Program for International Development, Clark University, Worcester, Massachusetts.

Bharara, L.P. 1977. Socio-economic consequences of canal irrigation in an arid district of Rajasthan. *An. Arid Zone* 16(4):458-472.

Biswas, A.K.; Hady Samaha, M.A.; Amer, M.H.; Abu-Zeid, M.A. (eds). 1980. *Water management for arid lands in developing countries.* Pergamon Press, Oxford.

Boyko, Hugo (ed.). 1969. *Saline irrigation for agriculture and forestry.* Dr. W. Junk N.V. Publishers, The Hague.

Bradley, D.J. 1977. Health aspects of water supplies in tropical countries. In: *Water, wastes and health in hot climates.* R. Feachem; M. McGarry; D. Mara (eds.), p. 3-17. John Wiley and Sons, Inc., London.

Commoner, Barry. 1971. *The closing circle.* Alfred A. Knopf, Inc., New York.

Coward, E. Walter. 1977. Indigenous institutions and irrigation development in southeast Asia: current knowledge and needed research. In: *Farm water management for rice cultivation.* p. 113-130. Asian Productivity Organization, Tokyo.

Dregne, H.E. (ed.). 1977. *Managing saline water for irrigation: planning for the future.* Proc. Int. Salinity Conf., Lubbock, Texas, August 16-20, 1976. Texas Tech. Univ., Lubbock, Texas.

Ehlers, Eckart. 1977. Social and economic consequences of large-scale irrigation developments - the DEZ Irrigation Project, Khuzestan, Iran. In: *Arid land irrigation in developing countries: environmental problems and effects.* E.B. Worthington (ed.), p. 85-97. Pergamon Press, Oxford.

El-Ashry, Mohamed T. 1980. Ground-water salinity problems related to irrigation in the Colorado River basin. *Ground Water* 18(1):37-45.

Eldridge, Edward F. 1963. Irrigation as a source of water pollution. *J. Water Poll. Contr. Fed.* 35:614-625.

FAO. 1978. *1977 FAO production yearbook.* FAO Statistics Series No. 15, Food and Agricultural Organization of the United Nations, Rome.

FAO/UNESCO. 1973. *Irrigation, drainage and salinity.* Hutchinson and Co., Ltd., London.

Favar, M.T.; Milton, J.P. (eds.). 1972. *The careless technology: ecology and international development.* Natural History Press, New York.

Feachem, Richard; McGarry, Michael; Mara, Duncan (eds.). 1977. *Water, wastes and health in hot climates.* John Wiley and Sons, London.

Freeman, Peter H. 1974. *The environmental impact of a large tropical reservoir.* Office of International and Environmental Programs, Smithsonian Institution, Washington.

Goell, A.; El-Rais, M.; El-Wahide, A. 1977. Use of highly-saline water in citrus irrigation. In: *Managing saline water for irrigation: planning for the future.* H.E. Dregne (ed.), p. 236-245. Texas Tech. Univ., Lubbock, Texas.

Hardan, A. 1977. Irrigation with saline water under desert conditions. In: *Managing saline water for irrigation: planning for the future.* H.E. Dregne (ed.), p. 165-169. Texas Tech. Univ., Lubbock, Texas.

Hotes, Frederick L.; Pearson, Erman A. 1977. Effects of irrigation on water quality. In: *Arid land irrigation in developing countries: environmental problems and effects.* E.B. Worthington (ed.), p. 127-158. Pergamon Press, Oxford.

Houston, Clyde E. 1977. Irrigation development in the world. In: *Arid land irrigation in developing countries: environmental problems and effects.* E.B. Worthington (ed.), p. 425-432. Pergamon Press, Oxford.

Israelson, O.W.; Hanson, V.E. 1962. *Irrigation principles and practices*, 3rd Ed., John Wiley and Sons, Inc., New York.

Johl, S.S. (ed.). 1980. *Irrigation and agricultural development.* Pergamon Press, Oxford.

Kassas, M. 1980. Environmental aspects of water resources development. In: *Water management for arid lands in developing countries.* Biswas, A.K.; Hady Samaha, M.A.; Amer, M.H.; Abu-Zeid, M.A. (eds.). p. 67-77. Pergamon Press, Oxford.

Katzenelson, E.; Buium, I.; Shuval, H. 1976. Risk of communicable disease infection associated with wastewater irrigation in agricultural settlements. *Science* 194(4268):944-6.

Laurence, B.R. 1977. Entomological and helminthological aspects of sewage treatment in hot climates. In: *Water, wastes and health in hot climates.* R. Feachem; M. McGarry; D. Mara (eds.). p. 284-298. John Wiley and Sons, Inc., London.

Li, M.; Fleck, R.A. 1972. *The effects of agricultural pesticides in the aquatic environment, irrigated croplands, San Joaquin Valley.* Office of Water Programs, Pesticide Study Series 6, U.S. Environmental Protection Agency, Washington.

Lipe, W.N.; Wilke, O.; Newton, O. 1977. Freeze protection of peaches by evaporative cooling in the post-rest, pre-bloom period. *J. Am. Soc. Hort. Sci.* 102(3):370-372.

Massoud, Fathy I. 1977. Basic principles for prognosis and monitoring of salinity and sodicity. In: *Managing saline water for irrigation: planning for the future.* H.E. Dregne (ed.), p. 432-454. Texas Tech. Univ., Lubbock, Texas.

McJunkin, Frederick E. 1975. *Water, engineers, development and disease in the tropics.* U.S. Agency for International Development, Washington.

Obeng, Letitia. 1977. The viewpoint of UNEP. In: *Arid land irrigation in developing countries: environmental problems and effects.* E.B. Worthington (ed.), p. 437-438. Pergamon Press, Oxford.

Odinga, R.S. (ed.). 1979. *An African dam.* Ecological Bulletin #29, Swedish Natural Science Research Council, Stockholm.

Panday, R.S. (ed.). 1979. *Man-made lakes and human health.* Proc. Conf., October, 1977. Univ. of Suriname, Paramaribo.

PCI. 1979. *Patterns in irrigation projects: an analysis of AID's automated data.* Practical Concepts, Inc., Washington.

Rosenfield, P.L.; Bower, B.T. 1978. Management strategies for mitigating adverse impacts of water resource development projects. *Prog. Water Tech.* 11(1-2):20-43.

Saliternik, C. 1973. *Water quality in Israel.* Israel National Committee on Biosphere and Environment, National Council for Research and Development, Jerusalem.

Sorber, C.A.; Guter, K.J. 1975. Health and hygiene aspects of spray irrigation. *Am. J. Public Health* 65:47-52.

Steinberg, D.I.; Caton, D.; Holloran, S.; Hobgood, T. 1980a. *Philippine small scale irrigation.* Project Impact Evaluation No. 4, U.S. Agency for International Development, Washington.

Steinberg, D.I.; Morrow, R.B.; Palmer, I.; Dong-il, K. 1980b. *Korean irrigation.* Project Impact Evaluation No. 12. U.S. Agency for International Development, Washington.

Strout, A.M. 1975. *World agricultural potential: evidence from the recent past.* MIT and Resources for the Future, Inc., Cambridge, Massachusetts.

UNESCO. 1961. A history of land use in arid regions. *Arid Zone Research XVII*, United Nations Educational, Scientific and Cultural Organization, Paris.

United Nations Secretariat. 1977. *Desertification: its causes and consequences.* Conference on Desertification, Nairobi. Pergamon Press, Frankfurt.

U.S.D.A. 1954. *Diagnosis and improvement of saline and alkali soils.* USDA Handbook 60, U.S. Soil Salinity Laboratory, U.S. Department of Agriculture, Washington.

USGAO. 1980. *AID must consider social factors in establishing cooperatives in developing countries.* ID-80-39, U.S. General Accounting Office, Washington.

White, G.F. (ed.). 1978. *Environmental effects of arid land irrigation in developing countries.* MAB Technical Notes 8, United Nations Educational, Scientific and Cultural Organization, Paris.

WHO. 1973. *Reuse of effluents: methods of wastewater treatment and health safeguards.* Tech. Report Series No. 517, World Health Organization, Geneva.

WHO. 1978. *Report on the seminar on the prevention and control of vector-borne diseases in water resources development projects.* VBC/EM/78.1, World Health Organization, Geneva.

Worthington, E. Barton (ed.). 1977. *Arid land irrigation in developing countries: environmental problems and effects.* Pergamon Press, Oxford.

Yaalon, Dan H.; Yaron, Bruno. 1966. Framework for man-made soil changes - an outline of metapedogenesis. *Soil Science* 102(4):272-277.

Yotopoulos, P.A. 1980. The strategy of irrigated agricultural development. In: *Irrigation and agricultural development.* S.S. Johl (ed.). p. 31-40. Pergamon Press, Oxford.

VIII ANNOTATED BIBLIOGRAPHY

This short bibliography includes the best references, in the opinion of the author, for the assessment of social and environmental impacts of irrigation development. The selection was made after reviewing over 300 references for the preparation of the guidelines.

The annotations are the opinion of the author and are not endorsements by the Man in the Biosphere Programme or the United States Agency for International Development.

Biswas, A.K.; Hady Samaha, M.A.; Amer, M.H.; Abu-Zeid, M. (eds.). 1980. *Water management for arid lands in developing countries.* Water Development, Supply and Management, Volume 13. Pergamon Press, Oxford.

This reference includes papers from a training workshop on water management for arid regions, sponsored by the Ministry of Irrigation, Government of Egypt, in cooperation with the United Nations Environment Programme, 2-14 December 1978 in Cairo. Noteworthy papers include a global perspective by A.K. Biswas; soils, salinity and waterlogging by M.M. Elgabaly; and on-farm water management improvement by M. Abu-Zeid. Papers also include technical discussions of modeling for aquatic environments, river systems and groundwater. Papers are generally brief and well written, but usually restricted to the Near East.

Dregne, H.E. (ed.). 1977. *Managing saline water for irrigation: planning for the future.* Proc. Int. Salinity Conf., Lubbock, Texas, 16-20 August 1976. Texas Tech. Univ., Lubbock, Texas. 624 p.

A superb collection of papers on salinity, waterlogging, alkalinity and water management. Papers vary from general to technical and policy to application of specific techniques. An excellent reference for irrigation planners.

FAO. 1971-1979. Irrigation and Drainage Papers (33 current titles). Food and Agricultural Organization of the United Nations, Rome.

Currently there are thirty-three volumes covering a range of irrigation-related topics, including yield response to water, groundwater pollution, water quality, agro-meteorology field stations, crop water requirements, farm water management, modeling, laws and planning. Most titles are available in English, Spanish and French. Information is comprehensive and technical, directed at engineers, agronomists, hydrologists and soil or water scientists. Exceptional references for water resource development planning.

Favar, M.T.; Milton, J.P. (eds.). 1972. *The careless technology: ecology and international development.* Natural History Press, New York. 654 p.

The classic reference for eco-development. These papers emphasize the negative aspects of development, but serve as excellent reminders for the need for environmental assessment in development planning.

Feachem, Richard; McGarry, Michael; Mara, Duncan (eds.). 1977. *Water, wastes and health in hot climates.* John Wiley and Sons, London. 399 p.

An exceptional reference on health and disease in the tropics. The various papers present information on types of disease, mode of transmission and practical control measures. Further, the book addresses social, political and economic aspects of health programs in the tropics. Most papers are directed at people without medical training, or extensive experience in tropical regions. It is a most useful reference for water resource development planners.

Johl, S.S. (ed.). 1980. *Irrigation and agricultural development.* Based on an International Expert Consultation, Baghdad, Iraq, 24 February-1 March 1979. Pergamon Press, Oxford. 370 p.

The papers in this reference focus on the United Nations Economic Commission for Western Asia (ECWA) covering socio-economics, environment, irrigation efficiency, crop water requirements, yield response, water quality, land reclamation, rehabilitation and specific case studies. Of special value are the papers on strategy of irrigated agricultural development, appropriate crop technology, selection of irrigation method, water for agriculture, crop and yield response, and irrigation efficiency. The papers are technical and provide excellent reference data for planners and environmental scientists.

MAB. 1979. *Trends in research and in the application of science and technology for arid zone development.* MAB Technical Notes 10. United Nations Educational, Scientific and Cultural Organization, Paris. 53 p.

A brief review of the characteristics and potential of arid zone resources with a record of recent research trends. The book also examines research needs for arid zones and how research should be applied to development of the resources.

White, G.F. (ed.). 1978. *Environmental effects of arid land irrigation in developing countries.* MAB Technical Notes 8, United Nations Educational, Scientific and Cultural Organization, Paris. 67 p.

This reference covers both the positive and negative effects of irrigation in developing countries. Based on an international expert workshop, the book provides a concise summary of the effects of irrigation from the viewpoints of experts in water resource development. The overview of irrigation is brief, but comprehensive, suitable for experts and non-experts in irrigation.

Worthington, E. Barton (ed.). 1977. *Arid land irrigation in developing countries: environmental problems and effects.* Based on the International Symposium, 16-21 February 1976, Alexandria, Egypt. Pergamon Press, Oxford. 463 p.

Includes a summary of the main effects and problems of irrigation based on the discussions of a joint working party at the symposium. In addition, specific papers by international experts on hydrology, land use, soil, water, biological balances, irrigation efficiency, human problems and the international viewpoint are presented. The papers, ranging from the highly technical to general readership, are excellent and provide a valuable overview of irrigation development.

Yaron, B.; Danfors, E.; Vaadia, Y. (eds.). 1973. *Arid zone irrigation.* Springer-Verlag, New York. 434 p.

Although somewhat dated, this collection of papers is still very valuable as an irrigation planning reference. Papers are quite technical, covering water-soil-plant relationships in detail. It is a very good foundation reference.

APPENDIX I

ENVIRONMENTAL DATA CHECKLIST IRRIGATION PLANNING AND EVALUATION

RATIONALE

Environmental and social assessments are more effective if data are collected, organized and presented in a systematic format. This can be accomplished through the development and use of an environmental data checklist (including social factors) for assessment, planning and evaluation.

The checklist proposed here includes data and duties which are, or should be, parts of a comprehensive environmental analysis for irrigation planning, implementation and evaluation. The checklist is structured into land, climate, water, agriculture, public health, biota (flora and fauna) and social categories, which are further structured into the following categories of development:

- Proposal or Pre-feasibility;
- Planning and Design;
- Implementation (construction);
- Operation and Maintenance.

This checklist can be used to identify the information desirable for assessment and planning. It can also be used to "scope" or define the environmental studies required for assessment and planning. Further, the checklist can be helpful in evaluating the sufficiency and reliability of available data for irrigation projects, or to organize the information for use by technical consultants.

Checklists are comprehensive, but rarely inclusive because compromises to length must be made. Also, there must be a concession to reality, since all the items in an inclusive checklist would never be available in the amounts and detail requested. Rarely, if ever, has any irrigation project had the resources to match the requirements of this proposed checklist and this is likely to hold true for the immediate future. Users of the checklist will have to determine if missing data or detail is crucial to their assessment and make the necessary compromises required in the normal development process. It is hoped, however, that each concession for missing data or duties included on the checklist is compensated by improvement in other parts of the checklist.

I. PROPOSAL OR PRE-FEASIBILITY STAGE

A. Land Information

_____National or regional map showing project area boundaries (1:50,000 - 1:100,000 scale);

_____Topographic map - project area (1:25,000 - 1:50,000 scale 3 - 7m contour intervals);

_____Large scale soil map - project area (1:10,000 - 1:25,000 scale, soil suitability);

_____Aerial photographs - project area (stereo-pairs, if possible);

_____Narrative description of the geomorphology of project area;

_____Soil survey data - project area (slope, texture, structure, infiltration rate and soil chemistry);

_____Drainage characteristics of project area.

B. Climate

_____Graphs showing monthly average temperatures (closest long-term meteorological station);

_____Graphs showing monthly average precipitation (closest long-term meteorological station);

_____Graph showing monthly average evaporation rates (closest long-term meteorological station);

_____Wind roses showing annual average of wind direction (closest long-term meteorological station);

_____Short-term meteorological data taken at a project area station;

_____Number of continuous frost-free days (potential growing season).

C. Water

_____Map of all surface waters (scale corresponding to area topographic map or air photos);

_____Chart of surface water sources
(area, volume of standing water; high, low and average flow of moving water);

_____Map of project watershed and present land use;

_____Ground water map of project area
(or data on available ground water surveys indicating depth to ground water);

_____Location of potential impoundment sites (if required);

_____Water quality data (surface and ground water)
Total dissolved solids, pH, electrical conductivity, sodium absorption ratio, residual sodium carbonate,boron and coliform tests (MPN). Sediment load of surface sources.

D. Project Agricultural Information

_____Present agriculture - project site
(type of crops, rotations and methods);

_____Proposed crops for irrigation
(types, rotations);

_____Proposed methods of irrigation;

_____Potential requirements for biocides and fertilizers;

_____Principal crop pests.

E. Public Health

_____National disease statistics;

_____Summaries of existing public health surveys
(project area or nearest survey area);

_____Size of human population and characteristics
(project area - age, sex ratios);

_____Inventory of available health services
(project area - staff and facilities);

_____Present water supply and methods for excreta disposal
(project area).

F. Flora and Fauna

_____Historic and current accounts of flora and fauna
(project area or environs);

_____List of potential endangered species
(from range maps or scientific expeditions);

_____ Local use of fish, game and native plants
(Market surveys, personal accounts);

_____Map of natural, undisturbed or forest areas
(from aerial photos, if present);

_____Map of existing protected forests;

_____Assemble national forest and wildlife legislation.

G. Social and Economic Data

_____Plan for improved community participation;

_____Maps or narrative description of existing land use and
demographic history (project area);

_____Land tenure (pattern and type of land use);

_____Indices of local economy and commerce
(per capita income, class structure, local markets);

_____Indices of education level;

_____Inventory of educational services
(project area);

_____Chart or description of local government;

_____Description of transportation network;

_____Record of migrations (human and livestock);

_____Inventory of non-agricultural resource use
(wood cutting, fishing, hunting, tourism).

II. PLANNING AND DESIGN

A. Land Information

_____Topographic Map - project area
(1:10,000 - 1:25,000 scale, 2 - 3m contours);

_____Detailed Soil Map - project area
(1:5,000 - 1:10,000 scale - soil families and soil
series);

_____Refined bedrock geology map - project area;

_____Expanded soil survey data - project area (physical components - slope, texture, structure, infiltration tests; chemical components - pH, cation exchange capacity, electrical conductivity, sodium absorption ratio and amount of organic matter);

_____Natural drainage data - project area (patterns, depth, rates);

_____Plan for monitoring soil changes.

B. Climate

_____Daily record of maximum - minimum temperature - at project site;

_____Daily record of precipitation - at project site;

_____Daily record of hours of sunlight - at project site;

_____Daily record of evaporation, Class A pan - at project site;

_____Daily record of hours and direction of wind - at project site;

_____Daily record of relative humidity - at project site.

C. Water

_____Map of project water sources;

_____Ground water map of project area;

_____Continued data on standing volume or surface flows;

_____Amount of sedimentation in surface sources;

_____Continue water quality test data;

_____Plan for monitoring post-project water quality.

D. Agriculture

_____Crop water requirements for proposed crops;

_____Water volume calculations for conveyance structures;

_____Plan for pilot or demonstration farms;

_____Estimates of area of cropland to be irrigated;

_____Preliminary agriculture extension plans;

_____Potential crop rotations;

_____Plan for water distribution and management (water users associations);

_____Plan for integrated pest management.

E. Public Health

_____Design criteria for irrigation structures to minimize health hazards;

_____Inventory of potential disease vector habitat;

_____Design criteria for impoundments;

_____Health criteria for water management;

_____Design for domestic water supply;

_____Design sanitation facilities;

_____Design for related health facilities;

_____Plan for public health education;

_____Plan for migrant health control;

_____Plan for monitoring post-construction disease status.

F. Flora and Fauna

_____Prepare reports of field surveys with expression of relative abundance of plant and animal species;

_____Report on extent of endangered species habitat;

_____Plan for protection of natural areas;

_____Develop reforestation or afforestation plan for watershed protection and erosion control.

G. Social and Economic

_____Complete community profile;

_____Plans for resettlement of human populations;

_____Plans for irrigated land allocation (consolidation);

_____Inventory of potential markets;

_____Plans for agricultural credit for farmers;

_____Plans for new or accessory transportation routes;

_____Plans for accommodating migratory humans and livestock;

_____Establish relief funds and supplies for farm families during project construction.

III. IMPLEMENTATION (CONSTRUCTION)

A. Land

_____Control erosion during construction;

_____Conduct compaction tests in agricultural areas;

_____Supervise construction;

_____Land-levelling controls - field checks (if appropriate);

_____Initial drainage design unmodified.

B. Climate

_____Operate agro-meteorological station;

_____Train agro-meteorological technicians.

C. Water

_____Revise water source maps;

_____Begin water quality monitoring;

_____Control erosion in construction;

_____Train water technicians;

_____Develop domestic water supply systems.

D. Agriculture

_____Pilot or demonstration farm trials;

_____Begin agriculture extension education;

_____Establish water users association;

_____Develop plans for inspection and maintenance of irrigation structures;

_____Establish necessary stocks of seed, fertilizer, biocides and tools for first planting season;

_____Develop integrated pest management program.

E. Public Health

_____Begin disease control program - vaccination;

_____Implement health program for construction force;

_____Implement health monitoring program;

_____Begin vector control program;

_____Construct health facilities;

_____Inspect structures for compliance to health design criteria;

_____Begin public health education;

_____Train public health technicians;

_____Monitor construction of project housing units;

_____Supervise construction of water supplies and sanitary units.

F. Flora and Fauna

_____Enforce wildlife protection regulations;

_____Establish nursery for tree seedlings for reforestation planting;

_____Begin protective measures for natural area preservation (signs, fences, education);

_____Maintain animal migration routes and access to water;

_____Identify native or exotic species for planting.

G. Social and Economic

_____Develop support for role of water users group;

_____Administer relief program for construction period;

_____Establish agricultural credit apparatus;

_____Administer resettlement and/or land consolidation program.

IV. OPERATION AND MAINTENANCE

A. Land

_____Monitor for accumulation soil salts;

_____Plant wind breaks;

_____Systematic inspection and maintenance of drains and conduits.

B. Climate

_____Continue agro-metorological station.

C. Water

_____Continue systematic water sampling and analysis;

_____Inspect and maintain conveyance system;

_____Implement weed control program;

_____Monitor water use.

D. Agriculture

_____Develop farmer's cooperative demonstration trials;

_____Continue research plots using different crop varieties and crop rotations;

_____Monitor irrigation efficiency;

_____Monitor crop yields, per unit of land and per unit of water;

_____Improve integrated pest management through pest surveillance programs;

_____Improve crop storage facilities.

E. Public Health

_____Continue comprehensive vector control program;

_____Conduct random epidemiological surveys;

_____Inspect and maintain domestic water supplies and excreta disposal systems;

_____Continue public health education;

_____Prepare and file periodic medical reports.

F. Flora and Fauna

_____Continue tree planting for wind breaks, watershed protection, fuelwood plantations and wildlife habitat;

_____Enforce wildlife regulations;

_____Continue surveillance for downstream effects.

G. Social and Economic

_____Continue to develop or improve markets;

_____Strengthen agricultural credit or crop insurance;

_____Maintain or improve transportation routes;

_____Strengthen general education program at adult and sub-adult levels.