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9. ABSTRACT

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A FRAMEWORK FOR EVALUATING LONG-TERM STRATEGIES FOR THE DEVELOPMENT OF THE SAHEL-SUDAN REGION

Annex 6

TECHNOLOGY, EDUCATION, AND INSTITUTIONAL DEVELOPMENT

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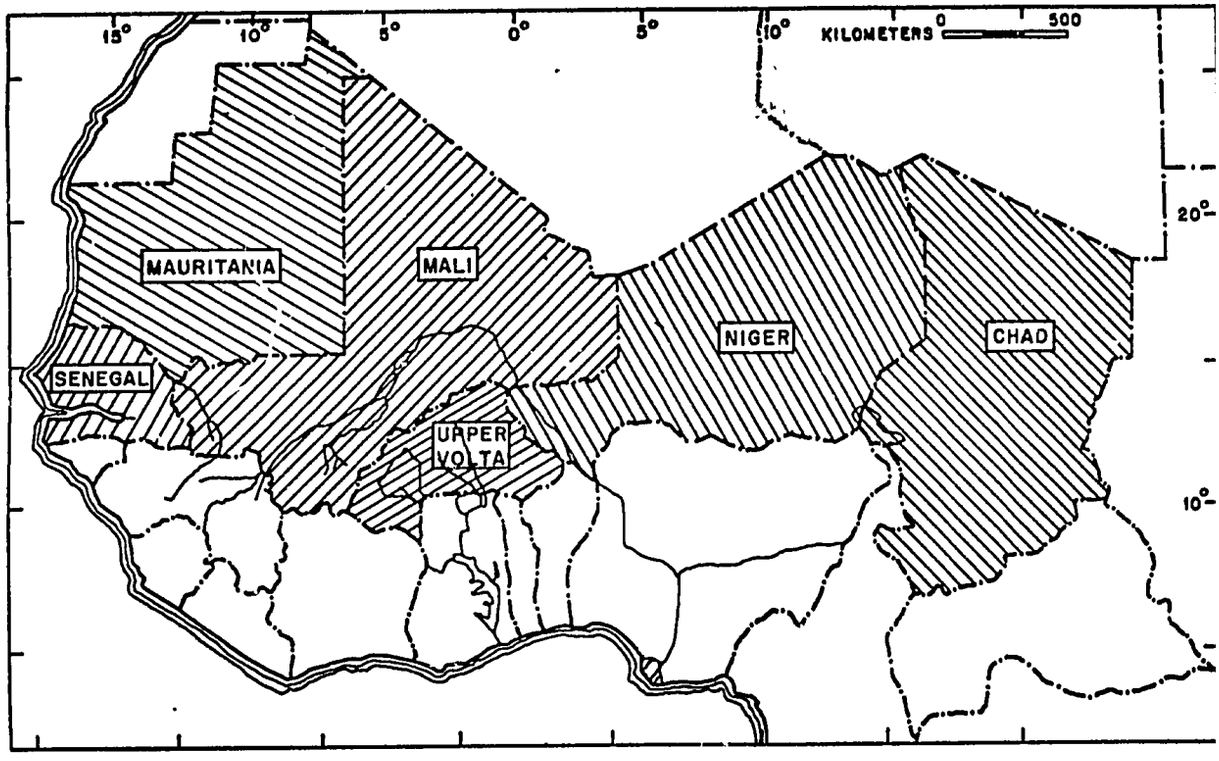

Volume 1. Summary Report: Project Objectives, Methodologies and Major Findings

Volume 2. ISYALAPS, A Framework for Agricultural Development Planning

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The contents of this report reflect the views of the Sahel-Sudan Project at the Massachusetts Institute of Technology and do not necessarily reflect the official views or policy of the Agency for International Development.

FOREWORD

This report results from a one-year effort by a multidisciplinary team of analysts to establish a framework for evaluating long-term development strategies for the African Sahel-Sudan area.

By June 1973 it had become evident that the suffering caused by the drought was the most severe the area had experienced in the last half century. A meeting of donor organizations and U.N. agencies, called by the U.N., was held in Geneva to discuss the problem. It was clear that, while the area required immediate assistance to meet the problems of drought relief, there was also need for long-range assistance if the region were to become self-sustaining and begin an era of positive economic development and widespread improvement in the quality of life of its people. The U.S. delegation offered to undertake the first steps necessary to "identify the methodology, the data requirements and the possible alternative lines of inquiry from physical, economic, social and cultural points of view" on which to base "a comprehensive examination of technical problems and the major alternative development possibilities" for the region.* The United States Agency for International Development (A.I.D.) offered to take responsibility for this task and determined that it should enlist the assistance of the academic community in carrying out the work. A.I.D. then approached M.I.T., and a study effort was formally initiated with the signing of a contract covering the period September 1, 1973, through August 31, 1974. This contract was subsequently extended to January 1, 1975.

The goal of the U.S. effort is to develop a methodology for evaluating long-term development strategies for the Sahel-Sudan region. The

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* Final Report on the Meeting of the Sudano-Sahelian Mid- and Long-Term Programme 28-29 June, 1973, Geneva. Special Sahelian Office, United Nations, New York. Statement by Donald S. Brown.

specific focus of the M.I.T. study has been on the development of an effective framework within which to appraise specific projects and programs. The term framework, in this context, refers to the accumulation, development, organization, integration, and analytical evaluation of information on the natural resources, economic resources, and human resources, including the social and political institutions, of the region. The framework is constructed in such a way that alternative strategies for the region can be identified and evaluated, in terms of both their requirements and their impacts, intended and unintended. The M.I.T. study has not been oriented toward detailed sector studies, prefeasibility studies, or project studies. Nevertheless, in the process of developing a methodology we have examined many kinds of information and a number of specific projects and have identified areas requiring further research to fill information gaps that impede long-range planning and evaluation of specific development proposals.

It is hoped that this framework will assist decision-makers in the Sahel-Sudan countries and in donor organizations in arriving at informed judgments concerning strategies for the long-term (20 to 25 years) social and economic development of the region.

The study was conducted under the direction of the M.I.T. Center for Policy Alternatives and was carried out by a multidisciplinary group. The Summary Report and the volume on agricultural development planning have drawn upon a number of working studies on specialized aspects of the problem prepared by the staff, i.e. (1) Economic Considerations for Long-Term Development, (2) Health, Nutrition, and Population, (3) Industrial and Urban Development, (4) Socio-Political Factors in Ecological Reconstruction, (5) A Systems Analysis of Pastoralism in the West African Sahel, (6) Technology, Education, and Institutional Development, (7) The Role of Transportation, (8) An Approach to Water Resource Planning, (9) Energy and Mineral Resources, and (10) Listing of Project Library Hold-

ings and Organizations Contacted. The basic elements of these studies have been drawn together in the two volumes of the final report.

In addition to M.I.T. personnel, individuals from a number of other organizations participated in the effort. Participants from the University of Arizona, in particular, made major contributions; they had primary responsibility for developing the analysis of the agricultural sector strategy. Professor John Paden of Northwestern University was a major contributor to the work on socio-political factors. Members of the Société d'Etudes pour le Développement Economique et Social (S.E.D.E.S.) in Paris provided valuable insights into various aspects of the Sahel-Sudan area. Several members of the Centre de Recherches en Développement Economique (C.R.D.E.) in Montreal developed sections on monetary policy, urbanization, and relationships between Niger and Nigeria. A list of individuals who participated in the study is included in Volume 1 of this report.

Numerous other individuals acted as consultants to the project, provided advice as the study progressed, and reviewed draft material for the reports. Help and advice were given by officials of the governments of the Sahel-Sudan countries, the Comité Permanent Inter-Etats de Lutte Contre la Sechèresse dans le Sahel (C.I.L.S.S.), members of United Nation organizations, members of the International Bank for Reconstruction and Dévelopment, and, especially, officials of the Secretariat d'Etat and various socio-economic and technical study groups in France. Finally, representatives of A.I.D. arranged meetings in Africa and reviewed the the progress of the study. All this assistance is gratefully acknowledged.

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This study of the role of technology in the Sahel-Sudan region is divided into three parts:

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Annex 6: TECHNOLOGY, EDUCATION, AND INSTITUTIONAL DEVELOPMENT

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SUMMARY AND CONCLUSIONS

As the attention of the world focuses on the tragedy brought on by the recurring droughts in the Sahel-Sudan region, technology is summoned to work miracles. Many people, including laymen, scientists, and engineers, believe that if sufficient funds were available a technical solution could be found for almost any problem. The successful development of the atom bomb and the space program are cited in support of the view that with national will and unlimited money, solutions can be found for most human problems.

This somewhat simplistic view of development is frequently used to justify technological "fixes" for the Sahel-Sudan region. However, several decades of experience with the LDC's has shown that even in countries with resource endowments far superior to those of the Sahel-Sudan, it is far more difficult than was first recognized to fashion a policy for science and technology, develop the mechanisms for the selection, promotion, and utilization of technology, and mobilize, on the one hand, the scientific and technological communities and, on the other, the entrepreneurial talents of the nation. Hasty application of technology, if not suited to the cultural traditions of the people or if based on an incomplete understanding of the ecology of the region, may produce disastrous consequences exacerbating the very conditions that technology was expected to ameliorate or cure. The need for thorough analysis and development of alternative planning policies cannot be sufficiently stressed.

This study of the potential role of technology in the Sahel-Sudan region is divided into three main parts. The major propositions emerging from each of the parts are summarized here.

Part I--Technological Solutions Proposed for the Problems of the Sahel Sudan:

—Both the level and the extent of application of technology in

the Sahel-Sudan are severely limited by a variety of factors. As a result, agricultural productivity is low and the human and material infrastructure necessary for the development of a substantial industrial base is lacking.

—Some interests for west African development tend to emphasize massive infusions of technologies and often imply that new or advanced "miracle" technologies exist. By and large, new or advanced technologies do not offer realistic solutions to the problems of the Sahel-Sudan because (a) they are too costly, especially when applied in a region where the required institutional infrastructure is not yet developed; (b) they tend to create what are referred to in developed countries as "bugs," but which may be critical new problems in countries with very limited resources; (c) simpler and cheaper technologies reaching large proportions of the population (such as may be observed in the Republic of Sudan) constitute preferable alternatives for the short term (5-10 years), although the usefulness of massive technological solutions might increase beyond that period, as the institutional systems and the human resources are developed.

—In addition to the purely agricultural technologies, which are not reviewed in this volume, the principal problem areas in which technology might have a special role are droughts and climate variability, water resources, energy, and health.

—In the area of climate variability, it appears that long-term weather forecasts and rainmaking techniques are still unreliable and that therefore their application will not have any significant impact on the development of the region in the near future. (It might even be counterproductive.) Further research is needed in this area. A research unit covering all of west Africa and supported primarily by donor countries could monitor weather and climate variations in order to develop a better understanding of the long-range climatic variations in Africa.

—It also is crucial to gain a better understanding of the

possible relation between the climatic changes in the Sahel and the pressures on the land. First results from an experiment conducted at M.I.T. suggest the existence of a self-reinforcing mechanism linking climatic changes to desertification due to overgrazing. The confirmation of the presence of such a mechanism would give added importance to the need for controls on grazing.

—Modern management techniques which take climatic variabilities into account are identified in this report in the areas of food, land, other natural resources and economic planning. That the Sahel-Sudan region could benefit from analyses that include climatic variability in economic planning is demonstrated by a Monte Carlo simulation model relating climatic variabilities and macroeconomic projections.

—In the area of water resources improved water management techniques could provide a major increase in agriculture production and reduce the risks associated with climatic variability. Technically it would be possible to add 50,000 hectares of year-round irrigated land annually during the next 15 years.

—More elaborate techniques involving reduction of water losses by evaporation, large-scale pumping of water, or desalination plants could become feasible beyond this 15-year period. The potential for year-round irrigated land might then become several million hectares.

The most interesting schemes employing large-scale technological developments in the area of water resources are the Ubangui-Chari and the west African waterways schemes. The first phase of what we propose as the Ubangui-Chari scheme includes long-term planning for water management in the Lake Chad Basin by strengthening the Lake Chad Basin Commission. Channels and levees would allow the irrigation of 400,000 hectares in average years and over 70,000 hectares under severe drought conditions. In the second phase the Logone-Chari waters would

be supplemented by waters from the Ubangui River, progressively over a 15-year period.

—The west African waterways scheme would be directed primarily to the control of the Senegal and Niger rivers. Support would be given to the Organisation pour la mise en valeur du fleuve Senegal (O.M.V.S.), the Liptako-Gourma Authority, and the Niger River Commission, to coordinate the development of the two rivers with agriculture and urban growth. The construction of the Manantali dam would be viewed as the first step to providing water for the irrigation of close to one million hectares, power for industrial complexes, and eventually a waterway from the mouth of the Senegal all the way to Port Harcourt on the coast of Nigeria. Since the problems directly related to the control of the Senegal River have already been the subject of many studies (e.g. Beyrard 1974), this section does not study them in detail.

—In the area of energy, the development of local resources other than wood would have important economic and social as well as ecologic implications. Artisanal and commercial units to produce methane from grasses and other cellulose products appear feasible. Their development and application could lead to the yearly recovery of more than a quadrillion BTUs, i.e., more than ten times the present total rate of energy consumption of the region (including wood). Fertilizers would also be obtained as by-products. Other promising applications of solar energy are presented in a schematic form and include compaction of grasses or plowing back into the soil. Further evaluation of these practices is needed.

—In the area of health, the opening of new land through disease-eradication programs would provide a significant, although less drastic, contribution to the development of the region. Such programs have already been started, with the assistance of the World Health Organization.

—Several other new technology-based development schemes are identified in this section: monomolecular layers to decrease evaporation losses from water surfaces; dirigibles to decrease the transportation costs of freight; nuclear complexes to provide water, fertilizer, and electric power; greenhouse irrigated agriculture; and hydroponics. However, the application of most of these technologies would reinforce the dual modern-traditional system and contribute very little to the real development of the region.

Our analysis also suggests that it is less important to find out which technology is useful than to understand how to accelerate true technological progress. Part II argues for "broad-based" technologies, i.e. technological development having significant social impacts. It also argues for the development of institutional capacity so that new technology becomes easier to assimilate and becomes directly linked to the social economic development of the region.

Part II--Choice of Technology: Forces Affecting Choice and the Decision Process

—A diagnosis of the present patterns of technology utilization shows a dual system with conflicts occurring between the traditional and modern technologies and indicates that modern technology has not yet contributed significantly to overall development.

—The development and implementation of an effective technological policy-making capacity is a long-term, low-yield process. Once such a capacity is in place, technological choices can be more easily delineated and related to national goals and objectives. Often these goals and policies are not stated explicitly, especially in countries where development planning experience is as recent as in the Sahel-Sudan.

—Technological choices responding to the urgent needs of a society should not be based on economic criteria alone but should also

include equity and quality-of-life considerations. Such a balanced development is difficult to achieve even under the best of circumstances, but nevertheless, in the Sahel-Sudan region, attention should be paid to these nonquantifiable criteria.

—In spite of the severe resource and manpower deficiencies that limit technological choice, the maintenance of continuity in development efforts is important to their success. This continuity can best be provided by the joint efforts of the national governments and development-oriented regional bodies, in whom decision-making is centralized for the region. Because of the centralized nature of decision-making and the lack of a substantial private sector, the political-technological decisions of governments in the region are likely to have far-reaching effects on the nature and rate of introduction of new technology. It is urgent, therefore, that governments of the region consider carefully the criteria for choosing the technologies appropriate to the region and the approaches to their implementation.

—In the analysis of Part II, two types of criteria are recognized: systems criteria and criteria for component technologies.

Systems criteria include contributions to institutional development, to structural changes, and to autonomy. Relevance and implementability are two other important systems criteria for making choices. Criteria for component technologies are introduced through a classification of technologies by type, sophistication, scale, and indigenousness. It is suggested that "grass-roots" or "broad-based" technologies affecting the welfare of large segments of the population be given priority over capital-intensive, "sophisticated" technologies that are of questionable feasibility and are expensive in terms of future research, development, and engineering costs.

—There is need to investigate the means by which local control over some of the critical factors in technological development can be

increased. An interactive simulation model is presented as part of the framework to evaluate policies and to provide a medium for discussing and generating ideas. The model can serve to identify critical factors and to structure information. Ideas not easily quantifiable, such as regional cooperation, political alliances, and influence of pressure groups, may be explored. The costs and impacts of assistance in the form of support for technological development may be compared with those associated with capital loans or food aid. The model is illustrated by a scenario.

Part III--Education and Institutional Development:

—The development of indigenous institutions for educational, scientific, and technological development emerges from this analysis as a high-priority objective. The educational systems of the region, which are the sources of the trained manpower needed for development, show all the characteristics of underdevelopment: low efficiency, high cost, and lack of relevance to the needs of development. The formal school system serves only about 15 percent of the school-age population. Substantial investments would be needed (a) to improve internal efficiency fo the school system, (b) to increase access to education by larger numbers of the young, especially from the rural areas, and (c) to increase the flow of skilled manpower for development.

—A "mix" of formal and non-formal education programs is needed. For the short term (5-15 years) non-formal education programs closely related to major development projects and hence to employment opportunities are likely to yield higher social benefits. Emphasis will need to be placed on the further development of a selected number of subprofessional technical training institutions, including institutions devoted to the training of second-echelon public servants and supporting personnel. Indigenous instructional manpower for these institutions is an urgent need that could be met by training substantial numbers of

technical teachers outside the region, especially in the coastal west African countries such as Nigeria and Ghana.

—Four types of institutions or programs that form the scientific-technological infrastructure of a country are distinguished: institutions or agencies devoted to (a) generation of knowledge, (b) formulation of policy, (c) application and diffusion of technologies, and (d) exploration, facilitation, and linkage of national, regional, and international agencies and programs. Investments in basic science might appear to be a luxury for poor nations, but sustained investments in basic scientific research are needed if a more profound understanding of the ecology, geography, geology, and climatology of the region is to be gained. The universities and the branches of former French research institutions in the region have an important role to play. A consortium of west African universities for research and training becomes an attractive, feasible alternative.

—A basic step in the development of national capacity for technological policymaking may well be programs for the improvement of public administration, especially for strengthening the ministries and the departments of planning, agriculture, industry and trade, and transportation. More elaborate national councils of technology and industrial research laboratories would become part of long-range development and become viable only if trained manpower in sufficient quantity and quality become available to the countries of the Sahel-Sudan region. There is already a plethora of regional institutions and agreements whose strengths and weaknesses need to be further assessed. The temptation to proliferate institutions must be overcome if limited resources are to be applied constructively. In the industrial sector, the identification of indigenous entrepreneurship and the development of banking and technical-assistance institutions and programs would be of interest to development agencies. There is much experience around the

world and among development agencies in the stimulation of small- and medium-scale industries, but this experience has to be sifted to isolate specific mechanisms applicable to the Sahel-Sudan region with its dispersed populations, traditional crafts, and traditional market structures.

—External agencies are likely to find that for the long term (25-30 years) the development of human resources, and through them the local institutions devoted to technological policymaking and implementation is an attractive, easily scheduled, and reasonably low-cost way of assisting the countries of the region. The identification of the critical institutions and the formulation of development plans in the education, health, agriculture, and transport sectors will need to be addressed on a sector-by-sector and institution-by-institution basis. There again the more advanced institutions in west African coastal countries may be looked upon as resource bases on which to build. Interconnections between institutions in the Sahel-Sudan countries and with institutions in west Africa can be established.

In addition to this paper, two internal reports on technology and education are available: (1) "Construction and Urban Housing Development in the Sahel-Sudan Region" by T. Fodor; (2) "Development of Education in the Sahel-Sudan Nations: The Colonial Legacy" by Linda S. Kadlec.

Part I

TECHNOLOGICAL SOLUTIONS PROPOSED FOR THE PROBLEMS OF THE SAHEL-SUDAN

Joseph E. Soussou

William W. Seifert

1. INTRODUCTION

The problem of the Sahel-Sudan region is not simply a problem of recurring drought, it is a more basic and complex problem of underdevelopment. New technological solutions are likely to be costly to the point of not being realistic. Moreover, they will generate new problems which may exacerbate the very conditions that they were expected to cure, as the mechanical pumps installed to supply additional water have generated problems of overgrazing and desertification. These new problems are more critical and more difficult to solve than the problems of insufficient water. This general characteristic of technological solutions generating new problems does not imply that they should be avoided at any cost. DDT was a great boon to some developing countries in spite of its later discovered damaging side effects. It is easier to ban it, or to develop substitutes, now that it has provided a needed function during critical periods of development and that the capacity to deal with these new problems has been developed. Hence, the increase of the capacity to absorb technology by a region in which this technology is applied should be commensurate with the rate of technology development. In order to avoid the situation of the sorcerer's apprentice, technological development should go hand in hand with institutional and human development

Caution in the utilization of new technology is on the minds of a large number of scientists and engineers from developed countries. Scientists from developing nations are more willing to ignore the risks associated with new technology. This trend may be observed, for instance, in the optimistic view towards new technology expressed by African scientists in a recent Delphi survey (UNESCO 1973). It may also be observed by African officials who are faced with an ever increasing number of feasibility studies as international agencies become more and more wary of undertaking any sizable project without guarantees of sufficient safeguards.

Studies for the development of the Senegal River Basin have already extended over more than a ten-year period, and more feasibility studies are still being planned. It is difficult to strike the proper balance between the rate of implementation of new technologies and the development of the local capability to understand their implications and their associated problems.

Part I of this report reviews the principal technological solutions which have been and are being proposed to cure the underdevelopment problems of the Sahel-Sudan region. By and large, the technologies which are needed in the Sahel-Sudan are simple and well-known. However, some of the more advanced technologies might give the region additional assistance in its development efforts in spite of the new problems which will probably ensue. Some technological fixes may provide the breathing period the Sahel-Sudan region needs to develop its human resources, namely its institutional and educational systems.

In the case of the Sahel-Sudan region, droughts and climatic variabilities are specific to the region and have exacerbated the more common problems associated with the state of underdevelopment. Therefore this review of the principal technological solutions starts with the area of climate variability. Section 2 discusses various technologies specifically related to droughts and climatic variability, i.e. weather monitoring and forecasting, weather modification, and management techniques dealing with the inevitable climate variabilities. The purely agricultural techniques, which constitute also one of the principal areas for the application of technology, are not included here. Volume 2 of the M.I.T. report series describes and evaluates them in detail. The other areas where technology might have a special role are: water resources, energy, and health. Section 3 reviews some of the large technological schemes in the water resources area. Section 4 suggests how local resources might be developed in the face of increasing energy costs and deteriorating balance of payments.

Section 5 briefly reviews some of the health related technologies. The last sections address themselves to a variety of other technology related issues.

2. TECHNOLOGY RELATED TO CLIMATE VARIABILITY

In an agriculture economy, weather is a critical factor. This is more so in arid lands because the variability of rainfall increases as the amount of precipitation decreases. Such variations include geographic and temporal (daily, seasonal, and annual) components. Typical of this variability are rainfall records at Agades and Tahoua which are both in the Sahelian zone of Niger and about 400 kilometers apart. During the years 1962 to 1968 which represent a pluvial period for the overall region, annual precipitation at Agades was continuously well below the ten-year moving average for the station. The Tahoua rainfall station, on the other hand, registered higher than normal precipitation in 1962, 1965, 1966, and 1967 (as high as 75 percent above average). Typical of arid zones is the fact that a storm may produce a large amount of precipitation in an area, while only a few hundred meters away, no rainfall occurs. Volume 2 of the M.I.T. report series shows the southward shift of the isohyets during the recent drought. Although this southward shift is important in some parts of the region (such as the western parts), in many other parts the drought appears to be mainly related to a change in the pattern of rainfall. Since weather, and more specifically rainfall has such a critical influence on the lives of the inhabitants of the Sahel-Sudan region, it is imperative to examine all the alternatives for weather control. Here the expression "weather control" implies the possibility of modifying the weather, long-term accurate weather forecasting, and various forms of adaptation to the inevitable climate variability.

2.1 Climatic Trends

It has been suggested that the climate in different parts of the earth is changing rapidly. In 1970 to 1973, severe droughts struck sub-Sahara in Ethiopia and the Sahel-Sudan region, while the Middle East had much more rain than usual, Siberia and the U.S. Midwest had colder than

normal winters, and "...in the height of summer 8 inches of snow was suddenly deposited on the wheat fields of the [Canadian] West" (Hoad 1974). Indications of long-term variations of climate extending over thousands of years have often been reported and were accepted as natural phenomena. However, a widely accepted view is that some climatic changes might now be induced by man's activities (Bryson 1973).

2.1.1 Long-term variations (time scale over a century): Long-term variations in the climate of the west African Sahel-Sudan can be deduced from historical writings and paleoclimatological studies. Written records reveal that 21 droughts of varying lengths have been reported over the past 450 years, i.e. an average of one drought every 21 years. Moreover, paleoclimatological records show that during the past 20,000 years the Sahel-Sudan has varied from much wetter to much drier than present conditions.

2.1.2 Medium-term variations (time scale on the order of a decade): Few stations with continuous weather records for more than 30 years exist in the Sahel-Sudan region. One of the longest records is from Dakar, Senegal, for the period 1887 to date. The analysis of rainfall records from three stations in Senegal led Landsberg and associates (1973a, b) to state that "...one would at least once in a century expect [statistically] a sequential series of 6 or 7 years with rainfall deficiencies, but there is an equal chance for many wetter years than the median." The recent 1974 season produced an above average amount of rainfall. This event led several experts to express the view that this is a sign that the drought cycle was broken, and that, following historical patterns, the coming seasons will also be wet.

At the Symposium on Drought in Africa, held in July, 1973 by the Center for African Studies at the University of London, various views about the future of the region were expressed (Dalby and Harrison Church 1973). Some predicted continued, long-term drought; others saw the

current drought as only another in a continuing series of drought-wet periods. For an extensive review of the climatic trends in the region, see Volume 2 of the M.I.T. report series. Our present view is that there does not seem to be a definite conclusion on climatic changes. Thus, in the absence of opposing proofs, one could argue that it should be presumed that by and large the climate in the Sahel-Sudan region has not changed significantly.

2.2 Climate and Weather Monitoring and Analysis

2.2.1 Weather monitoring: Climatic changes concern many countries and several years ago an international program was started--the Global Atmospheric Research Program (GARP). This program is sponsored by the World Meteorological Organization and by the national governments of the countries involved. In May 1974 an experiment known as the GATE (for GARP Atlantic Tropical Experiment) was initiated. The GATE experiment included 40 ships, gathering data mostly from the South Atlantic (Schmeck 1974). In addition, NASA launched a synchronous satellite to collect principally meteorological data over the Atlantic. This experiment will provide input important to the objective of an intensive 18-month effort to start in 1977 to develop a complete model of the climate of the world. At the present time, computers could not process the data required by such a model at a rate faster than real time. Modeling of long-term climate changes is still at an early development stage, and it may be several decades before such a complex task is mastered.

A group of several west European nations also established an organization in England for long-range weather forecasting in the area. Dr. Landsberg (1974) suggested the establishment of a similar organization in west Africa. Such a research unit would cover all of west Africa and might be supported primarily by donor countries. This unit could

develop from a strengthening of ASECNA* and its association with its counterparts established in English-speaking west African countries. It would monitor the weather and climate and try to develop a better understanding of the long-range climatic variations in west Africa.

2.2.2 Weather modeling: An important task of such a research unit would be the development of mathematical models representing the climate of the region. These mathematical models may be very useful for at least two tasks: (1) to provide a one to two month mean weather forecast, and (2) to assess the impact of large-scale man-made changes on the weather.

—Weather forecast: Some modeling effort of the climate of the Sahel-Sudan region has already been initiated. A report by the National Academy of Sciences mentions a model developed by Bryson (NAS 1974) which may be refined, and Rapp et al. (1974) used another model for simulation of the climate of west Africa. Besides the causal or mechanistic models mentioned above, better prospects are already showing up in the domain of statistical analyses. A recent analysis of rainfall data for Dakar by Landsberg (1974) shows a strong coherence of the spectra of sunspot activity and rainfall, especially for the 11 and 80 year cycles. Also a peak in the two to three year interval suggests a possible influence of the upper atmospheric wind oscillation in equatorial zones on the rainfall in the area. These findings suggest that although climate in the region is characterized by its marked variability, this variability might be to a large extent embodied in predictable cyclical phenomena. Nonetheless, the prospects for long-term weather forecasting are not very encouraging yet. It will probably be several years before models could predict with a meaningful level of certainty the mean weather characteristics two or three months in advance. Such forecasts

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*ASECNA: Agence pour le Securite de la Navigation Aerienne en Afrique et Madagascar

could include the total seasonal rainfall, and possibly its variability. These forecasts, even if possible in the near future, would have a limited value. They could help the countries to prepare for an oncoming drought by encouraging actions such as the organization of relief programs. However, one could argue that as long as the uncertainties attached to the forecasts are high, development planners are better off using long-term statistical records for the formulation of their programs. Development programs can account for information such as: rainfall will be below normal one year out of three, and five successive years of lower than normal rainfall are likely to occur once in a century with a given probability. However, it is more difficult to use in a development plan information such as: this coming season has 60 percent probability of having 10 percent below normal precipitation, and 40 percent probability of having 20 percent below normal precipitation. This is a situation similar to earthquake engineering: statistics from historical records can be useful to the building code of a region, while probabilistic forecasts of earthquakes might create social problems which would outweigh their benefit to society (up to the time when they become accurate and reliable).

—Man-climate interactions: It is our belief now that the so-called "southward march of the desert" is a poor expression for describing the progressive desertification occurring in the Sahel-Sudan. The movement of sand dunes is not the primary process of desertification. It is rather the variability of the weather which permits herd size increases to go unchecked and agriculture to expand northward during the wet years. An ensuing less-than-average-rainfall year forces a retreat of cultivation from the dryer areas, leaving them prone to land erosion and loss of fertility.

Simultaneously, the herd size which cannot be suddenly reduced, increases the pressure on the land. Overgrazing then reduces land carrying capacity, and accelerates the process of desertification. The fact

that climate variability intensifies the desertification processes has been well illustrated in a dynamic model constructed within the overall M.I.T. study on the Sahel-Sudan region (Annex 5). This model demonstrates that even in the absence of a major drought, the variability of the climate was inexorably reducing the land carrying capacity of the region, while population was increasing.

As mentioned above, an important use for weather forecast models is undoubtedly the study of large-scale man induced changes, such as the impact of a major dam on the climate of a region. Rapp et al. (1974) used such a technique to assess the climatic impact of a Lake Chad 100 times larger than present. Bryson (1973) tried to assess the impact of air pollution.

Weather forecast models seem to indicate that man's actions might be contributing to the "southward march of the desert." Charney (1974) used a computer model in a preliminary attempt to evaluate this process which has a long time constant. His theory is based on the observation that satellite pictures show the Sahara Desert to be a sink of heat during the month of July, i.e. this region loses more heat than it receives, when most of the northern hemisphere is a source of heat. This causes the air to compress, and consequently to dry, i.e. to reinforce the dryness of the desert. This observation led Dr. Charney to speculate on a possible reinforcing, or positive feedback loop between changes on the ground associated with the formation of some deserts and changes in the climate. This theory would link the desertification due to overgrazing to a reinforcing mechanism of xerification.

Satellite pictures show that animal grazing can produce large changes in albedo* of the area. The first results reported by Charney (1974) indicate that an albedo change might produce a significant change

*i.e. the ratio of the amount of energy reflected to the incident energy

of climate over the Sahel-Sudan region. A reduction of albedo was made from 35 percent (which is an arbitrarily high value since deserts have typically an albedo of 28 percent (M.I.T. 1971)) to 14 percent (which may be characteristic of the Sahel-Sudan) over an east-west strip over Africa (about 400 kilometers wide and several thousand kilometers long) north of the 18° parallel (latitude of Nouakchott). The numerical results produced about 65 percent increase in precipitation north of the 18° parallel, and about a 5° shift to the north of the ITCZ*. Although these results would need to be checked with a more refined grid and actual data, they point to the urgent need of evaluating this theory more accurately. For instance it would be useful to determine the albedo change which might have resulted from the drought and to evaluate the significance of the positive feedback loop between desertification and xerification. It would also be useful to test the theory against the historical records contained in ERTS photographs and older aerial photographs.

A definite evaluation of this theory is very critical since it has implications on land use and recovery times, and might possibly lead to the search for means to modify the albedo of large areas (e.g. vegetation, dyes, changes in amount of dust, etc.). For instance, it might be of interest to verify whether the large-scale brush fires (80 percent of the total area in the Sudan zone are burned over each year) reported from satellite observations have any negative impact.

2.3 Weather Modification

2.3.1 Large scale: Rainmaking techniques have been proposed as a means for increasing rainfall in the Sahel-Sudan region. However, rainmaking is a technique about which there is much controversy. It has been related that the U.S. Army used these techniques in Viet Nam

*Intertropical Convergence Zone--for further details concerning its role in the determination of the weather over the region, see Volume 2 of this report series.

at great costs and with inconclusive results (possibly a few percent increase in precipitation). It has been estimated that in Australia where the right type of cloud formations are present, an expenditure of approximately $4 per square kilometer could increase annual precipitations in some locations from 200 millimeters to 250 millimeters (UNESCO 1973).

Although these techniques are being improved with a better determination of the combination of characteristics which produces the highest probability of success of the operation (Project Skywater 1972), it can be said that by and large rainmaking techniques are still unreliable, very costly, and applicable to relatively small areas. For example, one report states that cloud seeding resulted in an estimated 21 percent loss of rain over a 100,000 square mile region in the U.S. (UNESCO 1973).

Statistical correlations between yield and rainfall based upon data from Niger (Verhaeghe 1974) show that the productivity of millet and corn increases by about 0.5 kilograms/hectare for each millimeter increase of rainfall around a base of 500 millimeters of precipitation. This estimate shows that if the conditions reported for Australia could be duplicated, an expenditure of $0.04/hectare would increase the yield by 25 kilograms/hectare, thus $0.80 would increase food production by the amount needed for an additional person. If these results could be achieved this would be a very inexpensive technique.

Modern rainmakers' techniques were applied in Niger in 1973 (Terramorsi 1973 and Weather Science, Inc. 1973) but the results were inconclusive.

Techniques for producing larger raindrops might increase the precipitation over areas where rainwater evaporates before reaching the ground. However, in view of the unreliability of the method, it should not be relied upon for the present time in the Sahel-Sudan region. Careful experiments should be conducted in order to understand better the local

atmospheric conditions, and avoid the possibility of creating costly precipitation in one area at the expense of another area. Paraphrasing Dr. Wendland (ASA panel discussion 1974): "it is like a toothpaste tube. Whenever you squeeze one part, you automatically create a bulge in a different part."

2.3.2 Small scale: Air-supported structures are now used to provide cover for areas ranging from small tennis courts to four-hectare stadiums. Enclosed areas using air structures or other domes would permit creation of a controlled environment and avoid the great risks associated with the capricious availability of rainwater in arid lands.

A proposal was made by Desert Domes, a British company for the creation of a community utilizing geodesic domes in a desert environment. The objectives would be to develop the technologies needed to fully utilize solar energy in a controlled environment to achieve self-sufficiency with a high degree of comfort. The development of various types of plastics and other lightweight low-cost materials has increased the feasibility of this concept. The cost of covers varies from $200/hectare for thin plastic films to $5,000/hectare for materials lasting 10 to 20 years (cost estimates from Desert Domes 1974). Although the con-concept of an integrated community living in a controlled environment is still too complex and too costly, the more specialized application to agriculture of small-scale environmental control is already realistic.

Several experimental applications have already been built in Mexico, in AbuDhabi, and at Fort Yuma, Arizona (UNESCO 1973). The University of Arizona has been involved in most of these projects. Data on the AbuDhabi project, which was reported in the UNESCO 1973 publication, suggest a water consumption of 1.5 liters/second which is 50 percent higher than the water needs in open field agriculture in spite of the water liner used to recycle water and nutrients. However, the

Mexico experiment using a controlled temperature, humidity and CO_2 content reports a water consumption of only 10 percent of normal. Experiments leading to improved yields and lower costs are currently under progress. It is reported that small changes in CO_2 content or the addition of hydrophilic polymers produce spectacular increases of yields (30 to over 100 percent increases). Present yields per crop in AbuDhabi for vegetables are two to three times open field yields in the U.S., with possibilities of more than three crops per year (60 tons of lettuce/hectare/crop). Although this technology is already technically feasible, it will be noted that the results of the UNESCO 1974 Delphi survey show that the African and international experts considered this technology as having only a marginal interest at the present time. A prerequisite for the economic feasibility of this technology, will certainly be a de-emphasis of the subsistence economy and an increase in the role of the trade economy. Implementation of this type of technology would not have any near-term direct impact on the problems of the drought. More likely, it would constitute like BUD in Senegal, a successful enclave industry oriented to foreign markets, with very little influence on social development.

Finally, it is interesting to make a simple cost comparison between covering a surface of water (part of Lake Chad) to avoid evaporation losses, and covering land for irrigation. It will be shown that covering one hectare of water to completely prevent evaporation losses would provide water for year-round irrigation of 2/3 of a hectare, yielding enough food for seven people. If environmentally controlled agriculture produces two to three times higher yields than in open field agriculture, then covering a hectare of land would produce enough food for 18 people (with only one-tenth as much water). Therefore, if only the costs of the covering structure are relevant, a covering for land could be two to three times as expensive as a cover for water and still be competitive.

2.4 Management Techniques for Climatic Variability

The previous discussions show that: (a) climate and weather in the Sahel-Sudan are characterized by their variability; (b) it will be many years before accurate and reliable long-term weather forecast models are developed; and (c) large-scale weather modification appears to hold little promise for increasing the rainfall in the Sahël-Sudan region, while use of domes to control weather over small areas offers possibilities of only limited interest. Hence, there is an obvious need to develop better means for coping with the inevitable weather and climate variabilities. It is principally soft technology, such as management techniques which may accomplish this task. We recognize four principal areas where improved management techniques could have significant impacts: food, land, other natural resources, and overall economic planning.

2.4.1 Management of food resources: Historically throughout the world grain has been saved for lean years. The Bible tells of storing food during the seven years of plenty in provision for the seven lean years. At least as early as the first centuries of the Christian era the Indians near the present city of Lima, Peru, had developed an extensive underground storage system for stockpiling grain for use in the lean years. And during the colonial years, villages in west African countries were required to store food sufficient for the equivalent of 100 days. Every year farmers brought in new grain in exchange for last year's grain. In the ensuing years various factors have contributed to more centralized forms of food storage. At present, this task is principally left to central governments, and in particular to the governments of the major grain producing countries. Although the F.A.O. tries to monitor the available reserves and forecast the needs, it does not have any significant power of intervention. As a result, countries and people who are at the ends of the distribution pipelines are likely to suffer. One

objective of the Food Conference of November 1974 was to agree on means to improve the monitoring capabilities of the F.A.O., and to modify the structure of the distribution pipelines so as to reduce some of the inequities. Nonetheless, improvements of world food management programs do not eliminate the need for regional and country programs.

2.4.2. Management of land resources: Range management, controlled fallow period, intercropping and soil conservation techniques are all practiced widely throughout the world. In this section we address the new technologies related to data acquisition and processing.

The study on "Energy and Mineral Resources" (Annex 9) emphasized the need for integrated planning in the development of natural resources. In the developed countries integrated planning is achieved because the strong institutional capacity which has evolved generates interactions among the economic sectors, geographical areas, technicians, decision makers, etc. New tools are now available to improve the efficiency of the strong institutional structures in tackling the increasingly complex problems of the present. The principal modern tools employed are those related to the acquisition and processing of information. Data acquisition is now greatly facilitated by applications of remote sensing. Moreover, computers play a critical role in speeding up the acquisition and processing of data relating to large geographical areas (such as the Sahel-Sudan) and by decreasing its cost.

Bale et al. (1974) prepared by U.S.A.I.D. a review of the applications of remote sensing to the Sahel-Sudan region. They suggested the following as principal applications of ERTS* technology:

(1) Update maps for the region (1/200,000)

(2) Prepare new geologic and tectonic maps

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*ERTS: Earth Resources Technology Satellite

(3) Study the movement of sand dunes

(4) Inventory surface and subsurface water

(5) Improve pedologic maps

(6) Inventory land resources

(7) Provide regional meteorological and climatological records to assist in forecasts and relief planning operations.

The costs associated with ERTS applications are highly variable. They include the costs of data acquisition, processing, interpretation, and verification. Satellite imagery costs of data acquisition are only one-tenth of conventional aerial photography costs. The total costs for ERTS imagery are estimated at $0.25 to $0.45 per square kilometer in the United States. They are likely to be much higher in the Sahel-Sudan region.

Because of the synoptic view it can provide, ERTS imagery may be invaluable for some applications. A widely publicized satellite photograph of a ranch in Niger, dramatized the effects of controlled grazing. Information needed to test new theories and models would be quickly available from a data base established with satellite pictures. For instance, the albedo data needed for testing the theory of a feedback loop between desertification and xerification could be obtained rapidly. Similarly, the evolution of desertification as a result of the pressure on the land could be monitored. Other advantages of ERTS technology are the reduction of the costs which must be borne by one user because the same images have many uses and the fact that the U.S. space program is already supporting the cost of launching the satellites.

However, ERTS imagery is only as useful as the information which may be extracted from it. For specific applications such as in cartography, one may appraise the value of updating existing maps and the economic feasibility of utilizing satellite imagery. But in general, the potential

benefits of ERTS technology are difficult to forecast. They are similar to the potential benefits of scientific research. A continuing effort involving the capacity for ground surveys, computer processing, and especially the interaction of planners, analysts, and scientists is absolutely required. Given the overall lack of institutional development in the Sahel-Sudan region, it would seem necessary to use sparingly the limited resources of the region in this technology. The cost of maintaining the capacity to effectively utilize the technique over a period of years would undoubtedly be excessive. As the local managerial and institutional capacity are developed, the potential benefits from ERTS technology will increase rapidly. Thus training of local people and a long-term modest support would seem to be appropriate.

Jones et al. (1973) examined the application of ERTS technology to assist the Liptako-Gourma Authority in its resources management program. Their conclusions tend to support our view of proceeding relatively slowly with the application of ERTS technology to the Sahel-Sudan region. They suggested several levels of support ranging from short-term, limited support of about $100,000 over one to two years, to a long-term support costing about 2,000,000 over 10-15 years. They recommended an assistance level of $250,000 for one year, in order to provide the services of technicians, vehicles and some photographic and related equipment. The results of this initial phase would be used to decide on the advisability of longer term support.

Thus, although ERTS technology will undoubtedly assist in the resource management of the Sahel-Sudan region, its potential benefits will be realized slowly and will depend primarily on the building of a strong local institutional capacity.

2.4.3 Management of natural resources: These resources include water, energy, and minerals. The energy and mineral resources study (Annex 9) and the water resources study (Annex 8) take a comprehensive

look at the technologies and management techniques needed to accelerate the development of these resources. In addition, section 3 of this report discusses some of the technologies related to water resources: small dams, levees, techniques to reduce evaporation from bodies of water, and advanced irrigation schemes such as sprinklers and drip water techniques. And section 4 will summarize the principal results related to energy resources.

2.4.4 Economic planning: A recent newspaper article (Rensberger 1974) was entitled "U.S. Agricultural Experts Find the Chinese Well Protected Against Famine." Besides high yield grains, inorganic fertilizers, intercropping techniques, etc., this report emphasized the manner in which the communes specialize in some crops, but simultaneously devote part of the land to insure a certain degree of self-sufficiency. From several reports on rural development in China (e.g. Aziz 1973), it appears that some of their success in keeping up with population growth in a rural society may be attributed to the communal structure which: (a) aims to achieve local self-sufficiency; (b) allows for the mobilization of the unemployed; and (c) provides the capacity for capital formation. In a way, the Chinese model is an example of the application of soft technology. Its success in keeping production apace with population growth and in coping with the variabilities inherent to agricultural production, makes it a model worthy of further study for adaptation in the Sahel-Sudan. Other models leading to the diversification of agriculture and of the economy as a whole should also be investigated.

In the more conventional methods of economic planning, we would like to emphasize the need to account for climatic variability. This is generally ignored in economic development plans which use average climatic conditions as a basis for their projections.

A Monte Carlo simulation program was developed in conjunction

with the Chenery-Strout model used in the macroeconomic analysis (Annex 1). This simulation program, which is presented in Appendix 1 accounts for the variability of rainfall. It also uses some data from the agriculture study (Volume 2) and yields the following conclusions:

(1) For a target rate of annual growth (5 percent), the actual annual rate of growth projected for Senegal until 1995 is 4.74 percent for the average climatic conditions, and only 4.14 percent (on the average) when climatic variabilities are accounted for. Therefore, if economic projections are made with average conditions, the rainfall values used should be somewhat less than the average rainfall. Otherwise projections will be overly optimistic.

(2) Under the condition of variable rainfall the variability of the projected rate of growth of GNP is somewhat less than the rainfall variability.

(3) Average requirements for foreign assistance necessary to achieve a given rate of growth of the GNP, are much higher (in this case double) than the requirements obtained from an analysis using average rainfall conditions.

(4) For individual simulation runs, the variability of required foreign assistance is very high. Therefore, foreign assistance should be highly flexible to adapt itself to varying climatic conditions.

We conclude by reasserting that the techniques to account for climatic variability in economic analyses already exist. Further details relating to the above illustrative example and typical results are included in Appendix 1.

3. WATER RESOURCES TECHNOLOGY

3.1 Africa's Central Lake

In prehistoric times, the Congo basin, an area of about 900,000 km^2, was covered by a lake of fresh water. Over 10,000 years ago, Lake Chad was much larger than its present size; it covered over 1,600,000 km^2, i.e. 100 times its present size. It is possible that water from Lake Congo seeped into Lake Chad at that time and maintained its level. It is also possible that the climate was different, and/or that it was influenced by these large bodies of water. At some point in time, Lake Congo broke its way towards the ocean in the narrow passes upstream of Kinshasa, in what is now known as the Chenal. This Chenal is 120 miles long; its width varies between one and two miles. The hills which border it have almost vertical faces. It is possible that the draining of the Congo Lake deprived the original Lake Chad of its main source of water.

In 1935 a German architect and engineer, Herman Sorgel, suggested damming the Zaire (Congo) River, somewhere between Kinshasa and the Kwamouth. The elaboration of this project is reported by Ley (1967). Figure I.3-1 shows the extent to which Lake Congo would be formed if the water level were to rise from the present 330 meters to 500 meters at the location of the proposed dam. However, the lake need not cover so much area and reach such a high level. Instead, it could be made to reach only 400 meters and then establish drainage outlets at specific locations, primarily north of Bangui. Such an outlet would spill the excess water into Lake Chad. Lake Chad would, in turn, cover an area of about 1,600,000 km^2 for an elevation of 340 meters and eventually overflow into the Mediterranean via a detour across northern Niger, northern Mali, southern Algeria, and into Tunisia.

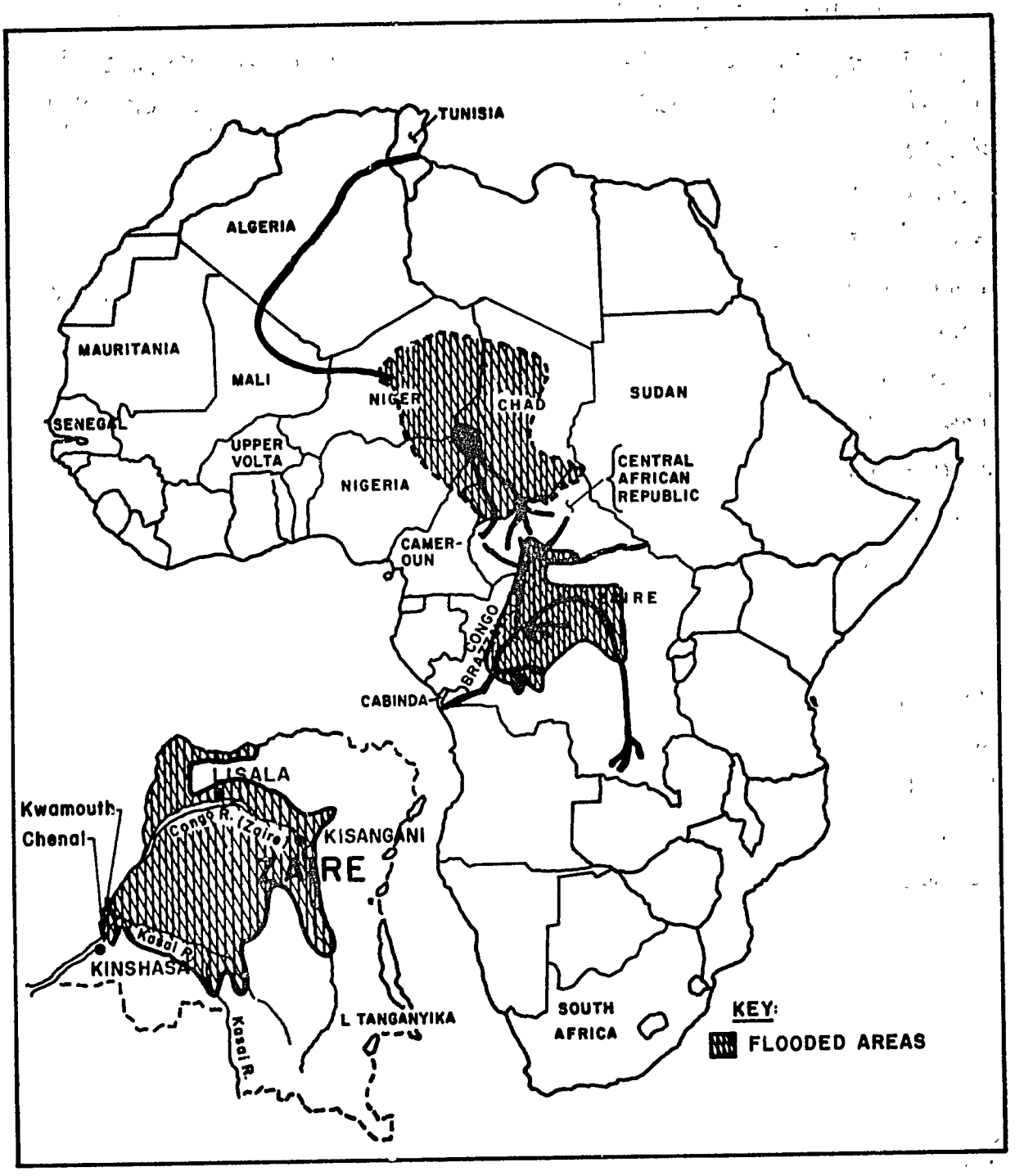

FIGURE I.3-1 Africa's Central Lake

The time needed for the realization of such a grandiose scheme can be evaluated. The Zaire River has an average outflow of 52,000m^3/second (Todd 1970), i.e., 4.5 billion m^3/day. One billion m^3 is the amount of water needed to cover 1,000 km^2 by one meter of water. Since the surface area of Lake Congo would be 900,000 km^2, it would take 200 days to raise the level of such a lake by one meter. Hence, the water would reach a level of 400 meters in about 40 years, and a level of 450 meters in 70 years. Of course, these are very crude estimates which assume that underestimation resulting from neglecting evaporation and infiltration is balanced by the overestimation of the volume to be filled by water. Once Lake Congo reaches the level of the outlet leading to the Lake Chad Basin, it might take an additional 90 to 120 years to cover an area of 1,600,000 km^2 (100 times the present area of Lake Chad) by an average of 30 meters of fresh water. This latter estimate assumes that three to four meters of water result in only one meter rise of the water level because of the high evaporation and infiltration rates.

Ley (1967) foresees even the possibility that the eventual overflow from Lake Chad into the Mediterranean Sea would occur through a navigable channel crossing the Sahara. His time estimate is about 50 years, which is one-third to one-fourth of our own estimates.

The principal benefits from such a scheme would be the greatly increased mobility across Africa, as well as the potential for agriculture and fisheries around Lake Chad. On the positive side is the claim that most of the drowned land is of little worth now. The 1,600,000 km^2 of such a Lake Chad might also be sufficient to modify the weather all over much of west Africa, probably to increase the rainfall. However, the impact of climate change would have to be assessed with computer models.

A recent report of the Rand Corporation (Rapp et al. 1974) used a computer model to assess the climatic impact due to the creation of such

a vast lake.* It showed that rainfall over equatorial Africa would be modified and that wind direction (but not magnitude), would be changed. The analyses were restricted to the months of January and February and do not seem to indicate any significant changes of rainfall over the Sahel-Sudan region (which generally occurs during the period extending from June to September).

The obstacles to such a scheme, aside from the capital required and time delay implied, are numerous. The principal one would certainly be the fact that this project extends over many political boundaries. Moreover, Zaire would have a large part of its national territory drowned, although it would be keeping the most valuable land (Figure I.3-1). In exchange, it would obtain very few advantages: modified climate (for better or worse?) and improved transport facilities (a lake replacing a jungle). In addition, it would have to relocate upward of two million people.

Overall, such a project has very little chance of ever being seriously considered.

3.2 The Ubangui-Chari Scheme

Examination of the topography of the Central African Republic, previously known as the Ubangui-Chari region, reveals that a narrow chain of mountain separates the Congo Basin from the Chad Basin. Figure I.3-2 shows the Ubangui River which is a tributary of the Zaire (Congo) River, and which runs along the border separating the Central African Republic from Zaire. At Bangui, the Ubangui River (French spelling: Oubangui) has an average discharge of 4,300 m^3/second (Rodier 1964

* This report speculates that the damming of the Ubangui River might create such a vast lake. Our estimates, presented below in the Ubangui-Chari scheme, are that the waters of the Ubangui River would raise the average level of Lake Chad by 4 meters only. Thus the size of such a Lake Chad would only be double its present size.

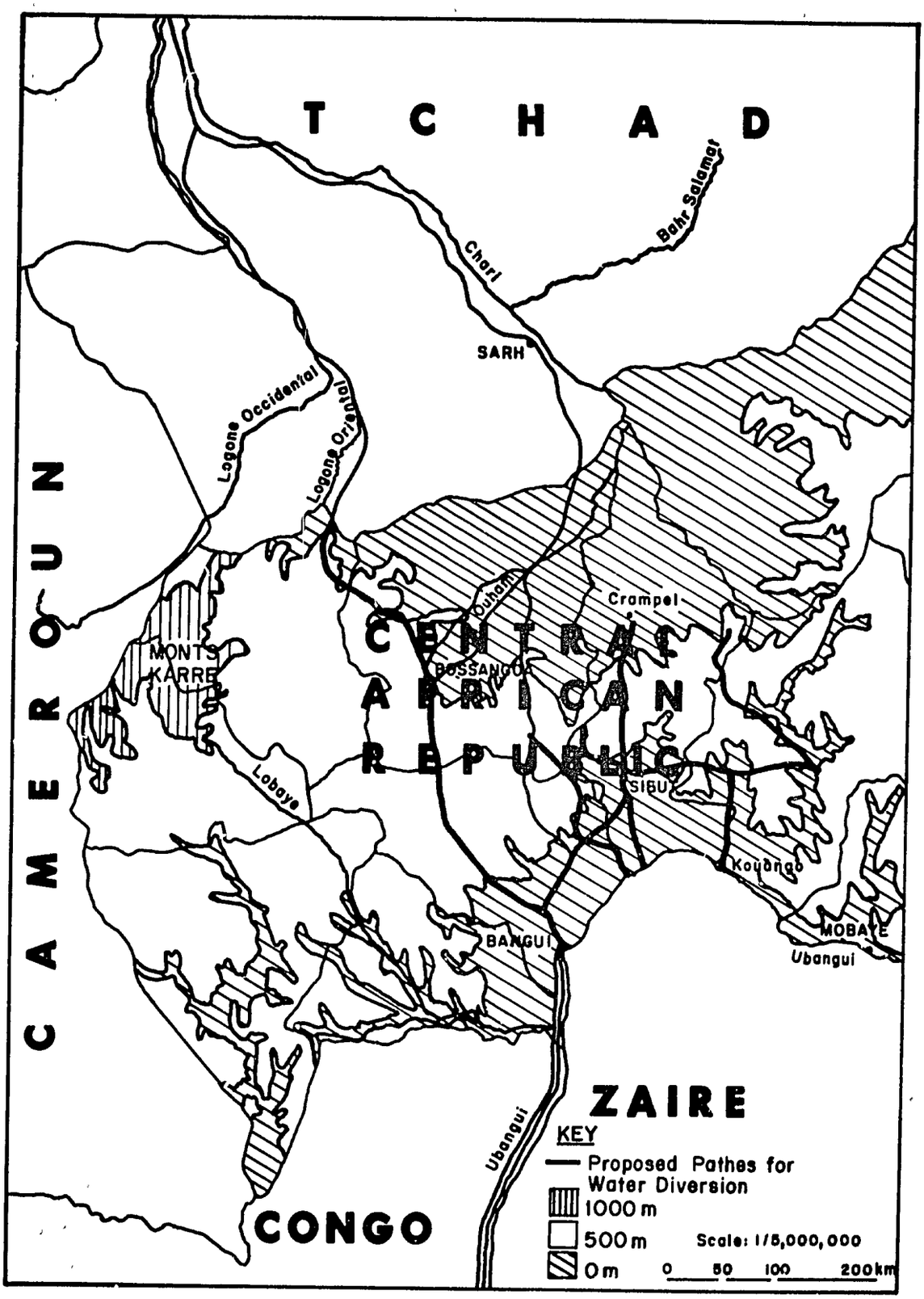

FIGURE I.3-2 Ubangui-Chari Scheme

gives 4,282 m^3/second, and Bultot 1971 gives 4,337 m^3/second). The elevation of the Ubangui River just before it reaches Bangui is about 400 meters, while the elevation of Lake Chad is about 280 meters. Some of the routes which lead from Bangui to the Chad Basin do not exceed an elevation of 510 meters. Since Zaire has a great excess of water, it would seem possible that it would agree to diversion of part of the Ubangui River through the Central African Republic and into the Lake Chad Basin.

The implementation of such a plan should be preceded by a more efficient utilization of the run-off water of Lake Chad Basin. The average total yearly inflow of Lake Chad equals 46 billion m^3. Most of this inflow is brought by the Chari and Logone Rivers. Lake Chad is shallow. Its average depth is about three to four meters, while its maximum depth is about ten meters. ORSTOM measurements, carried out between 1907 and 1972 (LCBC 1972), show that the annual average depth of Lake Chad varied between 2.5 and 5 meters, while its surface area varied between 12,500 km^2 and 24,000 km^2, and the volume of water varied between 15 billion m^3 and 55 billion m^3. We will retain the average values of: depth = 3.2 meters; surface area = 15,000 km^2 (the area of the states of Connecticut and Rhode Island combined); and volume of water = 23 billion m^3. These values correspond to the average loss by evaporation and infiltration of three meters of water annually, which balances the average inflow of 46 billion m^3 (an average flow of 1,470 m^3/second). Studies from LCBC (1972), show that if the average water level of Lake Chad were to be lowered by about one meter, it would be possible to irrigate 260,000 hectares because of the decreased evaporation. This calculation assumes year-round irrigation, i.e. one liter/second/hectare. Kirshen (1974) reports that projected dams regulating the rivers would add only about 2,000 hectares of irrigated agriculture. However, under drought conditions, irrigation will not be possible, even with the projected dams.

He also suggests that channels and levees along the Chari and Logone rivers would allow 400,000 hectares of year-round irrigation which could decrease to 70,000 hectares under drought conditions. The dams in this case would not be needed. Dikes would also be useful around Lake Chad in order to decrease its surface area and water losses. These dikes would make more water available, in addition to the water savings attributed to the channels and levees. Channels, levees, and dikes would be costly but would provide the needed security for drought conditions. Cost estimates could not be provided without detailed topographic data and some field trips. The levees needed to regularize the flow of the Chari and Logone and to decrease their water losses were estimated as follows. About 500 km of rivers lie between Lai and the lake. The maximum annual flow seems to be of the order of 2,000 m^3/second. The maximum allowable velocity in a channel should be of the order of three meters/second. Thus, the cross-section of the rivers would be about 650 m^2. If the width of the channel averages 200 meters, the height of the levee would be about 3.25 meters. The cost of levees determined in a study for Puerto Rico (Kirshen et al. 1974) was given as a function of water velocity and the height of the levee. Costs derived from that analysis would be $150,000/km, at 1972 prices. Adding 33 percent to this estimate because of the landlocked situation of Chad would yield $200,000/km, i.e. a total of $100 million. If this cost is allocated to the additional irrigated land it would be about $700/hectare of year-round irrigation under a drought-proof plan.

The idea of developing polders around the lake has also been proposed by SODELAC (Societe de Developpement du Lac). Their studies suggest that up to 150,000 hectares could be cultivated around the lake. Farmers use at present the waters of the lake either by waiting for the receding of the flood waters or by chadouf irrigation. They have to shift their cultures every few years because they do not use enough water to

wash out the salts. Flood waters, when they occur, make the soil useable again. In periods of sustained drought, the level of the lake becomes much lower and chadouf irrigation has serious limitations. The SODELAC proposes as a pilot project building three polders covering about 3,000 hectares. The water in these polders would be carried by concrete troughs and/or piping systems. Water would be pumped in when the level of the lake is low, and pumped out from central dams when the level is high. The estimated cost for these 3,000 hectares is about $5,000 per hectare.

Revelle (1974) suggested an alternative to the construction of polders. He proposed the use of more elevated lands in conjunction with a network of shallow hand-dug wells and small low-lift pumps. The principal advantages of this alternative are the following:

(1) lower cost per hectare--$1,000 instead of $5,000 for the SODELAC project;

(2) the development could proceed by small incremental stages;

(3) management of water distribution would be easy.

In addition to the levees and channels, the loss of water could be reduced in some parts of the lake. With the current drought, Lake Chad was split into four parts and it is conceivable to make some of these partitions higher and permanent. Then the water of part of the lake could be covered by a thin film of plastic or oil which could reduce evaporation losses, while fishing could take place in the remainder of the lake. Dyes might also be used. If evaporation loss is reduced by two meters each year, the water saved by a covered hectare of lake, could be sufficient for year-round irrigation of two-thirds of a hectare, i.e., to produce the food requirement of seven or eight people. The water lost by evaporation from Lake Chad could provide year-round irrigation for over 1.5 million hectares, i.e., produce the food requirements of over 15 million people. The cost of such a cover may be excessive. Thin plastic films would

cost about $100 per hectare, but would not withstand the winds. Monomolecular films (Todd 1970) decreased evaporation loss by various amounts: 30 percent over two hectares in east Africa, 1956; 30 percent over 12 hectares in Spain, 1958; and nine percent over 1,000 hectares in the U.S., 1958. Plastic beads have been used in west Africa but created problems for cattle drinking the water. Any technique reducing evaporation losses may be worthy of study.

The lake could also be depressed in some locations by the explosion of bombs placed under the lake. However, the blast may increase the losses by infiltration.

Following these improved water management practices, additional waters from the Ubangui River would maintain a higher level for Lake Chad, raising the potential of fish production and permitting stable irrigation practices less sensitive to drought conditions. Moreover, if the additional waters were also used to regulate the Logone, Mayo Kebi, and Benoue Rivers, it might be possible to maintain a year-round navigability for small boats between Lake Chad and Port Harcourt in Nigeria.

In order to estimate the required amount of water, we may consider first the record of the levels of Lake Chad in the last sixty years (LCBC 1972). It appears that average yearly variations do not exceed 0.5 meters, and that from one year to the next, the variations do not exceed 0.5 meters either. Therefore, in order to maintain the level of the lake constant with a surface area of 15,000 km^2, a maximum of 7.5 billion m^3/year is needed, i.e., a maximum annual average flow of 240 m^3/second. The benefits of maintaining a controlled level for Lake Chad would undoubtedly be beneficial to the fishing industry which was hard hit by the drought. This amount of water would only be sufficient for yearly variations. If several years of drought occur in succession, this water would only be sufficient to raise the water level of 0.5 to 1.0 meter higher than it would have been without any intervention.

If, in addition, one were to raise the level of Lake Chad, an ORSTOM formula (LCBC 1972) suggests that for every meter increase in the water level of Lake Chad, an additional 5,000 km^2 of land are drowned. Because of the high evaporation rate (2.5 meters/year) and possible infiltration rate (0.5 meters/year), more than four meters of water may be needed to drown additional land under one meter of water. Thus all the waters of the Ubangui River would not raise the average water level of the Lake Chad by more than four meters and would only double its present size. This assumption does not account for the overflow to Bahr-el-Ghazal which may occur at an average depth of about five meters. Therefore, all the waters of the Ubangui would mostly expand the surface area of Lake Chad and greatly increase the loss of water by evaporation and infiltration.

Instead, the water could be used to irrigate land, even during the drought periods. The high rate of insolation should permit wide-scale double cropping and produce very high yields. Since irrigation requires one liter/hectare/second, i.e. three meter head of water per year, the total flow of the Ubangui River (135 billion m^3/year at Bangui) would irrigate up to 45,000 km^2 (4.5 million hectares) in double cropping. This irrigated area represents about three times the size of the present Lake Chad, and does not need to be concentrated around Lake Chad. One hectare could produce enough food for ten people, under double cropping practices, and such an irrigation scheme could produce enough food for up to 45 million people. This extent of new irrigated land might also affect the micro-climate.

Therefore, the Ubangui-Chari scheme would include the following phases:

(1) Prepare the channels and levees in the Lake Chad Basin in order to irrigate up to 400,000 hectares in normal years and over 70,000 hectares under drought conditions. Also, use other techniques to reduce

evaporation losses. This phase might extend over five years.

(2) Supplement the Logone-Chari waters by waters from the Ubangui River (about 240 m^3/second) to control the level of Lake Chad and/or insure an additional 250,000 hectares year-round under drought conditions; raising the total irrigated land to 320,000 hectares under drought conditions. This phase might extend over fifteen years.

(3) The third phase might supplement the waters of the Mayo Kebi and Benoue flowing towards the Niger in Nigeria by 100 m^3/second. This phase would take place only if the diversion of the Ubangui waters passes in the vicinity of Lai and Bongor to complement the Logone. An overflow of the Logone waters into the Mayo Kebi and the Benoue rivers occurs in this vicinity. The additional 100 m^3/second, accompanied by major works of regularization of the rivers, could connect Lake Chad to the ocean by a navigable channel, possibly with locks.

(4) The last phases might increase progressively the 340 m^3/second diverted from the Ubangui River by an average increment of 50 m^3/second every year, raising the area of year-round, drought-proof irrigated land by 50,000 hectares every year up to a maximum potential of about four million hectares.

The diversion of some of the Ubangui waters might be accomplished by various means. The formulation of specific plans requires field trips and detailed data on the topography of the region. With the information that we have now, we can only speculate on various alternatives.

One such alternative would be to choose a location where the gradient of the terrain is high, for instance around Bangui. The water would be pumped in several stages to a high reservoir, from an altitude of 400 meters to an altitude of 525 meters. This would require a transmission line of about 200 km in length. If 240 m^3/second were to be transmitted as suggested in the first stage, at an average velocity of four meters/second, the cross-section of the pipelines would be about

60 m^2. Such a network of pipeline and associated pumps and reservoirs may cost about $1 million to $2 million per km. The total investment cost would then be of the order of $300 million, averaging $1,200 per hectare of drought-proof, year-round irrigated land. The power needed to pump the water can be evaluated at 575,000 hp or 440 MW. Larger magnitudes of water pumping are currently achieved in pumped storage in the U.S. to supply peak demands of electricity. Appropriate sites along the Ubangui River could provide this amount of hydroelectric power. From the high reservoir the water would flow by gravity in open channels and aqueducts to the Logone or the Chari River. The drop from the high point to Lake Chad would be about 250 meters. If appropriate sites are identified and 20 percent of the drop is used to generate power, about 100 MW could be generated.

Another alternative would be to collect the waters of the Ubangui River or some of its tributaries at a higher elevation in order to have a smaller head for pumping and to build a longer aqueduct starting somewhere upstream of Mobaye and extending over nearly 400 kilometers; or possibly build a dam on the Ubangui River (if an adequate site can be located) to raise the water level and shorten the required channel or pipeline. Estimates for their costs may be widely different. For instance, in the South San Joaquin Division--the huge California water project (Dewey 1966)--lifting 230 m^3/second of water by 300 meters and carrying it over 200 kilometers of concrete lined canals cost an estimated $1 million dollars per kilometer. These conditions are very similar to the first stage of the diversion of the waters from the Ubangui River except for the fact that the lift in the California project is twice as large. On the other hand, a 20 kilometer stretch in the California project including a lift of 600 meters for 150 m^3/second cost $9 million per kilometer because it included four tunnels. Therefore preliminary cost estimates may be highly variable.

Several other alternatives combining pipelines, reservoirs, tunnels,

channels, and aqueducts might also be identified.

This scheme is much more realistic than that of Africa's Central Lake. At least it does not result in large-scale disruptions and relocation of people.

Zaire could benefit from the sale of the hydroelectric power needed to pump the water, as an indirect manner of selling its water. The Republic of Central Africa would benefit from some of the hydroelectric power generated on the downstream part of the scheme, as well as from some water and possibly some royalty payments for the pipeline, or for its maintenance. Chad would benefit from a controlled level of the lake, helping the fishing industry as well as from drought-proof irrigated land producing enough food for the first phase of the plan for over three million people under drought conditions and twice as much in normal years. The first phase of the project might slightly affect the micro-climate around Lake Chad. Further development of the plan might increase the rainfall over other countries of west Africa and might provide a navigable link between Lake Chad and Niger.

3.3 West African Waterways

A major impediment to the socio-economic development of the Sahel-Sudan region is a marked lack of transportation and mobility. Usual economic criteria show that the transportation system is adequate for the volume of goods being transferred, and that large investments in it are not justifible by the increase in production, which might ensue from such investments. These economic benefits do not account, however, for the social and long-term economic benefits, which are difficult to assess. Indeed, the present transportation system may be adequate for the present socio-economic system, but some improvements may induce major social changes. One may argue that the lack of transport during the rainy season may in itself reinforce subsistence modes, since, to a large extent, each locality needs to be self-sufficient and cannot depend on trade.

Moving from a subsistence economy to a trade economy requires and is hastened by a good transport network accessible to a large fraction of the population. The presence of such a transportation network could have incommensurable impact on education in the broad sense of the word, as well as on social customs, urbanization patterns, development of trade and business, diffusion of agriculture techniques, etc.

Construction of paved roads is an expensive partial solution. In order to have the desired social impact, this alternative should be associated with large-scale ownership or utilization of vehicles. Capital outlays would be tremendous. An alternate solution might be the development and wide use of All Terrain Vehicles (ATV). Important savings on the capital requirement for the construction and maintenance of the transportation network may be achieved; however, the cost of subsidizing a wide range utilization of ATV's would be very high.

Another alternative to providing a transport system which may initiate revolutionary (i.e. very rapid) social changes, is the improvement of unpaved roads in order to make them passable all year round. This strategy should be associated with wide scale availability of cheap public transportation, as well as a broad ownership of private vehicles (animal drawn carriages, bicycles, and other man-powered vehicles, small utility carts and trucks, motorcycles, etc.). While this is an interesting transportation strategy applicable over most of the region, its costs and the infeasibility of a broad scale ownership of vehicles will represent major obstacles to its rapid implementation.

Another alternative, more restricted geographically, is the regulation and utilization of most of the west African waterways. Year-round navigation is possible over small stretches of the Niger and the Senegal River. During seven months of the year, the length of navigable waterways increases significantly (maybe doubles). However, as was discussed previously, the interruption of a transportation system, however small

that interruption is, changes drastically its social impact. This interruption may be temporal (for instance, one month a year) or spatial (for instance, the low bridge at Gaya/Malanville on the Niger, falls, or rapids).

When one observes Figure I.3-3, it may be seen that the Senegal River extends over more than 800 kilometers, the Niger River over more than 2,400 kilometers, the Volta rivers over more than 1,000 kilometers. The Senegal and Niger rivers might be connected by a channel extending, according to its location, over 250 to 500 kilometers. About 6,000 kilometers of navigable waterways could be made available. Figure I.3-1 shows that it is conceivable to have a year-round navigable link stretching from Dakar in Senegal to Port Harcourt in Nigeria and possibly from there to Lake Chad. The magnitude of the work is very large, but such waterways have constituted important inputs to the development of other parts of the world, such as Europe.

The potential benefits would be numerous. Among them is the partial unlocking of Chad, Mali, Niger, and Upper Volta. Wood, which is plentiful in the coastal countries, could be brought inland for firewood and for structural uses. Cattle (or meat) could be moved part of the way towards the coastal zones on boats, speeding up the transfer, and reducing weight losses. Most important is the fact that small boats could be produced locally in the coastal zones and would require only the import of diesel engines. Urban development would be planned along these waterways in order to use these axes for the shipment of goods, and to utilize hydroelectric power wherever it might be produced. Many urban centers are already located along these waterways: Saint-Louis, Kaidi, Bakel, and Kayes on the Senegal River; Bamako, Segou, Mopti, Tombouctou, Gao, Niamey, Onitsha, and Port Harcourt on the Niger River; Makurdi, Bongor, and N'djamena on the Benoue and on the Logone; and numerous urban centers along the Voltas.

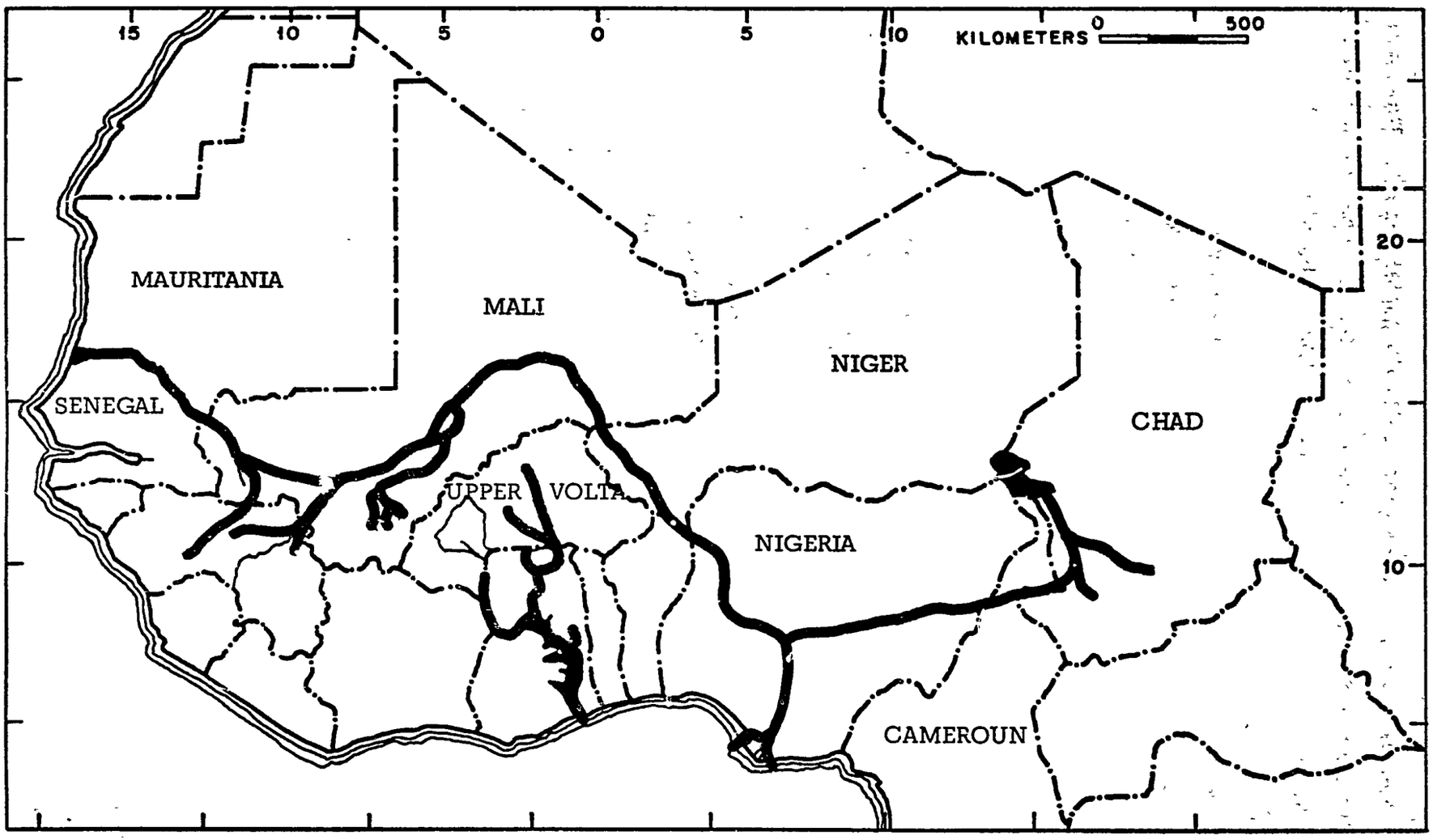

FIGURE I.3-3 West African Waterways

This technology-based scheme would regularize the principal rivers and interconnect them in order to make them navigable, as well as generate hydroelectric power and develop irrigated agriculture. Of course, trade-offs would have to be made. Presently recognized sites for hydroelectric resources may be about 800 MW as estimated in Annex 9 of the report. The total average annual flow of the Senegal River at Bakel is about 700 m^3/second, while the average annual flow of the Niger varies between 1,750 m^3/second near Bamako to 1,200 m^3/second near Tombouctou, to 1,000 m^3/second near Niamey, and to 2,100 m^3/second at the Kaindji Dam in Nigeria. Thus the Senegal and Niger could provide up to 1,700 m^3/second, a year-round irrigation of 1,700,000 hectares. More efficient techniques such as sprinklers or drip water irrigation might increase this figure by 50 percent. This is an upper limit since navigation, hydroelectric power production, limitation on land, and needs to flood some areas for the cattle industry, are all factors which may reduce this potential by as much as 50 percent. The present estimates for the Senegal River alone are over 300,000 hectares (Senegal Consult 1970) and it may be presumed that an effective water management scheme may result in 600,000 hectares along the Niger River. All of this land has a high insolation rate and some agriculture experts estimate that the region along the Senegal River might have the potential for the highest yields in the world. Thus, irrigation of over 900,000 hectares might complement navigation and produce the equivalent of enough food for 9 million people, in average years. The Lake Chad Basin might add another 400,000 hectares as discussed in the Ubangui-Chari plan.

Mining and related industries would also benefit from this plan, in addition to the increased trade, navigation potential and irrigation. Agro-industrial complexes might be planned in three three principal areas: around the Manantali Dam; in the Liptako-Gourma region; and in the basin of Lake Chad (if the Ubangui-Chari plan is implemented). These complexes

would use hydroelectric energy to process the already known mineral deposits (iron, manganese, copper, phosphate, etc.) and produce fertilizers and other agricultural needs. Proposals for such industrial complexes have already been offered by the O.M.V.S. and the Liptako-Gourma Authority. The capability of these organizations should be greatly increased. Another area where hydroelectric power, navigation and urban and industrial development might be coordinated is along the Volta rivers, from Upper Volta to Ghana, and to a lesser extent from Guinea to Mali. Ghana has the potential for producing more than 750 MW in the near future. For a long time to come, this will greatly exceed the needs of Ghana. Power can be transmitted now over high voltage DC lines quite efficiently. Several such transmission lines are in operation now in the United States.

The network of all-weather dirt roads would be conceived to feed in along the axes represented by the waterways. These waterways would also be supplemented by paved roads running along them and interconnecting them. Urban growth would take the form of a megalopolis of small urban centers sprawling along these waterways. High population density along these axes greatly enhances industrial development and the diffusion of information and goods (in times of drought). The principal benefit will undoubtedly be the increased rate of conversion from the subsistence economy to a trade economy with all its advantages.

If the population grows at a rate of two percent, i.e. about 500,000 people a year, increased food production would require the year-round irrigation of an additional 50,000 hectares each year to keep up with the food requirement, and possibly a two percent increase in the production of dry land agriculture to raise the level of the quality of life.

Given the potential indicated in this section on the regularization of rivers in the whole region, additional irrigated land might be increased at the rate of 50,000 to 75,000 hectares a year, keeping up with the increase

in population for at least 20 years if we neglect the improvements of dry land agriculture. Beyond that period, increases in the efficiency of water utilization are possible, as well as increases in yields, and the gradual shifting to higher value crops. By then, industrial production might also represent a significant input to the economy.

Cost estimates for this plan would require more detailed studies.

4. ENERGY TECHNOLOGY: CONVERSION OF GRASSES

The costs of energy represent a serious obstacle to the development of the Sahel-Sudan countries. Local energy sources are available but they are untapped since they are not generally in a form readily utilized by conventional means. Less than two percent of the potential hydroelectric power (1,000 MW) is harnessed. Besides this relatively small amount of hydroelectric power and geothermal energy sources, the principal local energy resources are sun and wind. This subject is dealt with in more detail in the energy and mineral resources section of the overall M.I.T. report (Annex 9), where the subject of energy policy formulation and evaluation is discussed more completely. This section will excerpt only the most interesting results.

4.1 Solar Energy

Solar energy is one of the principal resources of the region. The principal methods of utilizing solar energy are summarized in Figure I.4-1.

The major technological developments for utilizing solar energy, which have the potential of having a significant impact on the region before the end of the century, are photovoltaic conversion and bio-cells for the direct use of sun energy, and methane and single cell protein production via photosynthesis. It is to be noted that these technologies differ from the above large schemes not so much by the magnitude of the required investments but by the fact that they do not have geographical constraints and could reach most of the populations.

4.1.1 Direct conversion: Among the applications of direct solar energy conversion are solar collectors for cookers, stills, and water pumps. Although these applications have certainly the potential of benefiting the Sahel-Sudan region, the energy models described in Annex 9 suggest that their direct economic impacts are limited, although their social impacts could be invaluable. The other important applications

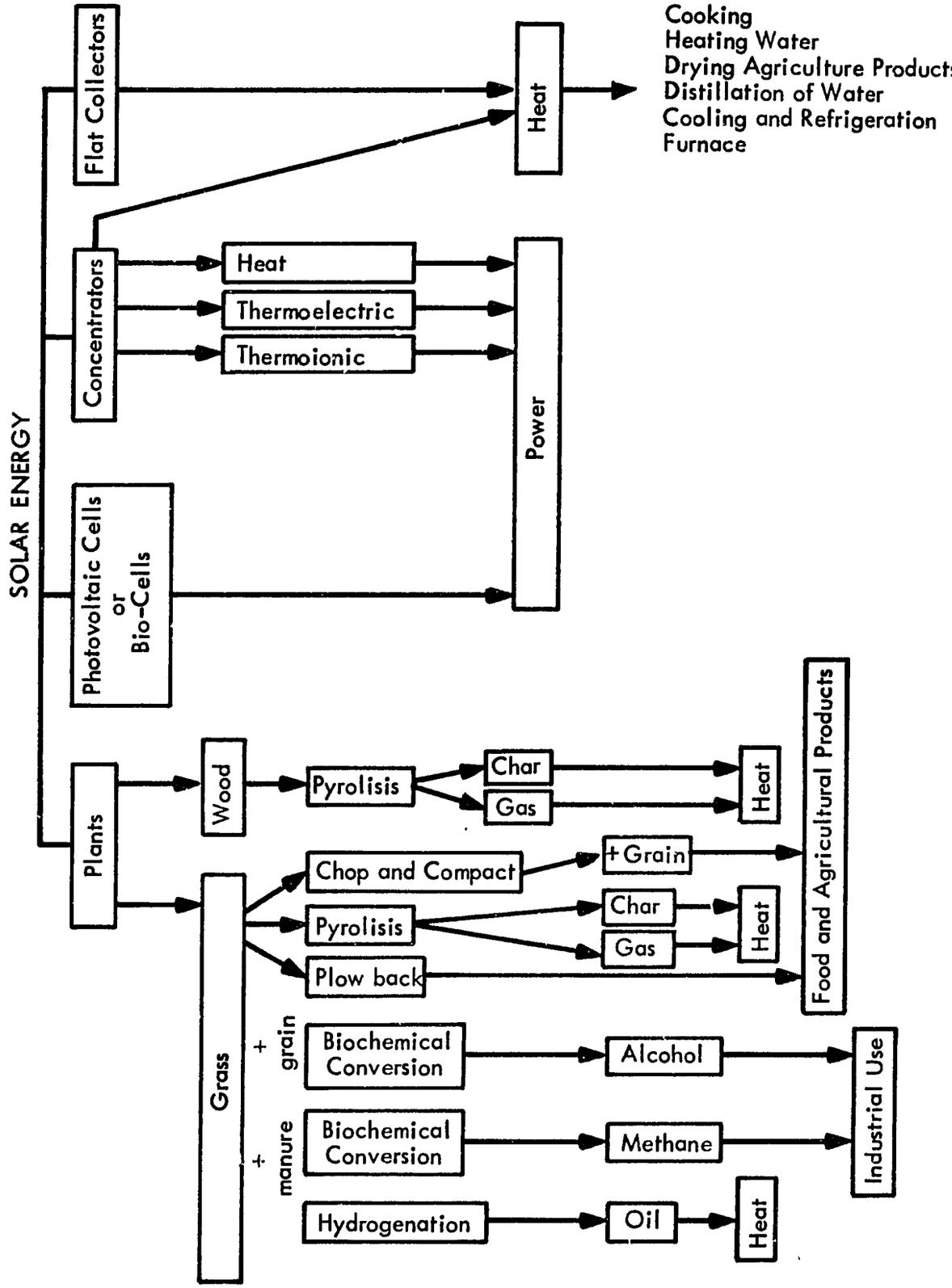

FIGURE I.4-1 Various Utilizations of Solar Energy

of direct solar energy conversion are:

—Solar cells, which convert solar radiation to electricity, have been used in the U.S. Space Program and schemes involving power stations on satellites orbiting the earth have been suggested. However, these latter are not likely to become feasible before the last decade of this century. Other schemes using silicon cells are being discussed but the costs range from $270,000 down to $400 per kilowatt (UNESCO 1973). NASA estimated its costs at $270,000 per kilowatt in 1972 and hoped to reduce this figure to $50,000 per kilowatt by 1978. NSF hopes to achieve $5,000 per kilowatt by 1977 and $500 per kilowatt by 1979 (Rosenblatt 1974). Japan is planning an expenditure of $3.6 to $7 billion on its Sunshine project between now and the year 2000: a one MW system should be completed by 1980, a ten MW system by 1986 and a 100 MW system by 1991. Several processes are under study to develop cheap ways of manufacturing the needed silicon film from sand. When one observes the drop of prices of computers and calculators, it appears that new processes and mass production would make this method of energy production useful to the region in less than two decades. Unfortunately, this is a possibility over which west African countries have little if any control.

—Bio-cells: Chlorophyl donates electrons to certain semiconductors. Work done at the Argonne National Laboratory suggests that it may be possible to duplicate some of the processes used by plants to convert light into energy and that artificial leaves may be possible within a decade (Salisbury 1974). Costs may be one percent of present silicon photovoltaic cells (UNESCO 1973).

4.1.2 Photosynthesis: Agricultural crops, livestock and wood are natural ways of using the energy of the sun. However, only 1/20,000 of the incident solar energy is retrieved in wood.

—Single cell proteins (SCP) produce food and feed rapidly by

making better use of solar energy. These can be produced from oil, agricultural waste and other refuse. Humphrey (1973) mentions the concept of village level technology in addition to the high level technologies. This concept is advanced by Tate and Lyle, Ltd., a sugar company. The design includes a $50,000 unit producing three tons of SCP per day.

More research is on-going in several universities in the United States. One such process uses the hydrolysis of wood to produce glucose, which is fermented to produce a yeast strain. This technology and the following one are probably the most interesting for the region because of the large amounts of solar radiation and the availability of agricultural wastes and unused grasses. Projected costs of proteins produced by these methods are still high but appear to be cheaper than usual proteins (beef, pork, eggs, etc.).

—Grass: Estimates of the burnt grasses and agricultural wastes indicate that these represent a potential of 1.5×10^{15} Btu/year, i.e. 12 times total present energy consumption (including wood), or 0.38×10^{15} Kcal, i.e., several thousand times the present agricultural production. Besides the production of food and feed, these wastes can be used to generate methane or alcohol by bio-conversion. This process is well-explained in "Methane Digestors" (New Alchemy Institute 1973). It produces fuel fertilizers. This is an extremely useful technology, since it can be developed in small artisanal units. Taiwan has 7,500 working simple farm installations. These are associated with pig raising schemes (Department of Rural Reconstruction, Taiwan). Larger units can be used to serve urban areas. The energy produced can be stored in the form of gas which can be carried in bottles. Commercial production does not need to be centralized but can be spread throughout the region. This form of energy is obtained almost entirely from local resources and does not need the enormous infrastructure of distribution lines. It could be well-suited to urban and industrial energy needs, in addition to farm production. In

the U.S. this is mostly interesting for reducing urban wastes. The model presented elsewhere in the M.I.T. report shows that the development of such local resources could have a significant impact on balance of trade problems. Note that in addition to a versatile fuel (methane) the process generates fertilizers.

The production of alcohol is more expensive and generally not justifiable for its use as fuel, but may be desirable for other chemical applications. Other efficient uses for grass include: plowing to increase soil productivity, chopping, packing and distribution as fuel.

4.2 Aeolian Energy

Wind energy might be used in large parts of the Sahel-Sudan region. Commercially available windmill generators on the order of one to three kilowatt produce electricity at about $0.15 per kilowatt-hour which is cheaper than the cost of electricity in some parts of the Sahel-Sudan. Design techniques could reduce costs for small power generating units, by using local materials such as cloth or wood. In spite of the obvious advantages of introducing wind power for pumping water, supporting artisanal activities, and saving wood, the direct economic impacts would be significant only if wind power is used for urban, industrial and commercial applications. The technology to produce the 100 kilowatt to 1,000 kilowatt units which would be needed, is not as much developed as the technology for the one to ten kilowatt units. There is presently a renewed interest in the United States for large production units, and it is probable that 1,000 kilowatt aeolian units will be used at an earlier stage than their solar counterparts. NASA, Grumman, and Vertol are working on the design of efficient windmill generators, using lightweight materials and electronic controls. The NASA is starting with a 100 kilowatt unit and planning a 1,000 kilowatt and 5,000 kilowatt unit (Business Week 1974). Large units are also being developed in

other countries, such as the U.S.S.R. Large aeolian units could be commercially developed in a relatively short time and could help the balance of trade problems of the Sahel-Sudan region.

Two problems associated with wind energy production are: storage of electricity and siting of the windmill. Lead batteries are used for storage but have limited capacities and are expensive. New technologies include: compressed air systems, pumped hydraulic storage, super flywheels and the electrolysis of water to produce hydrogen for use as a fuel (Wade 1974; Hammond et al. 1973). Site selection requires extensive meteorological data collection and local wind surveys to take advantage of local topography. Hourly records may be needed for a year or two (U.N. 1962).

4.3 Nuclear Energy: NUPLEX

Some of the characteristics of nuclear energy make it interesting as the basis for development of an agro-industrial complex. These characteristics are (1) the great flexibility afforded in its location since it is not constrained by the transport costs of fuels, or the location of a natural energy resource; (2) the low cost energy which is produced; and (3) the possibility of using the low value heat energy to produce water at about $0.20 to $0.30 per 1,000 gallons, i.e., about $0.06 per cubic meter (UNESCO 1973). The concept applies principally to coastal zones such as Mauritania and Senegal where power and desalted water would be produced. The power would be used to support a chemical and metallurgical industry, and the water would be used for year-round irrigated farming. Such a complex sometimes is referred to as a NUPLEX. Many studies involving such complexes have been carried out. One of the studies of the Oak Ridge National Laboratory (1968) sees important economic advantages especially in developing countries. They project internal rates of return higher than ten percent for a small complex (500 MW).

Using an estimate of 200 gallons of water a day to produce requirements of one person, they estimate food production to cost $0.03 per day with an initial investment of $165 per person.

"Cost estimates for a projected Egyptian agriculture-based complex are $3.4 billion (70 percent of this for a closed irrigation system. Operation and maintenance $0.8 million per year," (i.e. 63 m^3/second) (UNESCO 1973). An evaluation of the feasibility of such a complex for Pakistan, was made at M.I.T. (Ahmad 1973). This study shows that the nuclear complex would provide 275 million gallons per day (12 m^3/second) to produce 0.5 million tons of food grain and fiber in addition to 400 MW of electrical output. The completion of the project would take about 12 years and require a total investment of $323 million with an internal rate of return of 10 percent. If no electricity is produced the water output would triple. This study suggests that the initial capital investment to produce food for one person could be about $200 if one-third of the capital investment is allocated to the production of electricity. This cost includes $80 for land development, irrigation systems and needed equipment. We can reduce these figures to the assumptions used as a basis for comparison in this report: one liter/second of water provides year-round irrigation for one hectare, and produces 5,000 kilograms of agriculture products equivalent to the annual food requirement of ten people. With these assumptions the nuclear complex described for Pakistan would provide the required water at a cost of about $10,000/hectare of year-round irrigation, making such a complex relatively more costly than the Ubangui-Chari scheme. The combined differences of assumptions for water requirements, yields, and food requirements produce more than a ten-fold variation in the estimates.

The results of a UNESCO Delphi survey show that African and international experts do not think that this type of complex would be of any interest to the African countries because it still needs a long development

period, it requires large amounts of capital and it is principally applicable to coastal countries (UNESCO 1974).

5. HEALTH RELATED TECHNOLOGY: DISEASE ERADICATION PROGRAMS

The World Health Organization (WHO) is already involved in several programs in the Sahel-Sudan region. Its principal program is the eradication of onchocerciasis in Upper Volta, in the basins of the Volta rivers. This program is estimated to provide an additional one million hectares for the settlement of 600,000 people (WHO 1973). The total cost of the program is about $100 million, i.e. about $165 per person settled. The cost estimates vary from a low of $87 per person for one project to a high of $405 in another project. These capital investments have internal rates of return varying between 10 percent and 17 percent per year. Under these conditions, this large-scale program compares advantageously with most of the larger scale irrigation schemes. However, at its full extent, the program would only accommodate an additional 600,000 people which is equivalent to the annual population increase in the Sahel-Sudan region.

The control of animal trypanosomiases could have a much greater impact on the region. If we assume that the presence of tsetse flies limit the potential livestock operation in the Sudan and Woodland zone, i.e. almost 1 million km^2, then it would appear that the elimination of animal trypanosomiases could raise meat production by a spectacular amount. Matlock and Cockrum (1974) suggest that about 25 percent of the area could be used for livestock production and that the carrying capacity could be about 55 animal units/km^2 while offtake rates could be sustained at 31 percent and the percentage of dressed meat over 50 percent. Under these conditions, the animal production of meat could be 2.6 million kilograms. Using the assumption of 1,500 Kcal/kg and 2,000 Kcal/day/capita, this would provide the caloric needs of two million people, while it could provide for protein needs of about nine million people (one kg of meat provides 200 grams of proteins, and the minimum protein requirement is about 60 grams per day). Almost all of this meat production

would be in addition to what is already being produced in the region.

In order to control trypanosomiases, several actions would be needed. Moreover, research programs should be intensified in several areas (Orue 1968). Among the actions which may decrease the impact of trypanosomiases are the destruction of tsetse flies, the treatment of sick animals, the protection of healthy animals, the elimination of some of the transhumance and the increased use of species (e.g. N'dama) which are especially resistant to this disease.

It would be difficult to estimate the cost of total control of trypanosomiases. We can, however, estimate the costs of one of its principal components: the eradication of tsetse flies. Even the cost of such projects vary greatly with the method used, the ratio of area reclaimed over treated area, follow-up surveillance, the species treated, etc. Reports on costs vary from a low of $54/km^2$ in northern Nigeria to a high of over $1,000/km^2$ (leRoux) for the application of various types of insecticides. We will retain an average figure of $550/km^2$. Thus the initial investment would be $70 per person on the calorie basis or $15 per person on a protein basis. Eradication programs have to be followed up by new applications of insecticides or by the release of sterile insects. Based on the Northern Nigeria tsetse eradication program which cost $54/km^2$ over a seven-year period, we will assume that the initial investment has to be amortized over a seven-year period. Thus we may double the initial capital investment to make them comparable with the irrigation schemes which have a useful life of over 20 years.

In addition to the costs of eradication of tsetse flies, more investments would be needed to obtain these high values of meat production. In general, health programs for the human and animal population should be evaluated in conjunction with other programs. It is interesting to note that WHO experts have recently expressed their concern for the evaluation of health problems which would be associated with new development projects.

For instance, irrigation projects may increase the incidence of a given type of disease, and projects should be designed to reduce these incidence risks rather than wait for the completion of the project to apply the needed curative programs. Thus the move away from drugs, to non-medical preventive programs should be supported.

6. OTHER TECHNOLOGIES

Various applications of advanced technologies have been suggested to solve many of the problems of the region. For instance, dirigibles are described in the transport section of this study, to lower the transportation costs by a factor of two to four compared to jumbo jets. These dirigibles might help the landlocked countries in their imports of fuels and their exports of minerals, meats and agricultural products. However, here again, the development costs of such a transportation system would be too large to be feasible given the small volume of trade in the foreseeable future. Although many dirigibles have already been built, take-off and cargo handling are still in dire need of improvement. A new concept not yet developed is the use of helicopters as winches to load the containers on airships. However, more development is needed to adapt this technology. As in the case of most advanced technologies, the Sahel-Sudan region lacks the resources to support their development requirements. Besides, the limited size of the markets they constitute makes it uneconomical to justify the development costs of these technologies.

Another proposal, which has been "floating" around for awhile, is the idea of towing icebergs from the Antarctic to the west coast of Africa. The distance of about 4,000 miles would require a towing time of almost a year. It is claimed that under these conditions, melting losses would be only ten percent (UNESCO 1973), and that the world's largest tug could pull 60 million cubic meters to Senegal or Mauritania. A tug ten times more powerful could pull 6,000 million cubic meters in the same period of time. If it is assumed that the annual costs for the tugs are to be $3 million and $9 million respectively and that only 50 percent of the water will be ultimately recovered, the water costs would be $0.10/$m^3$ and $0.003/$m^3$ respectively ($0.45/1,000 gallons and $0.014/1,000

gallons). This water may be competitive with water obtained from desalination plants, but the costs will also be functions of the handling problems of the ice and the problems of its melting. At $0.003/m^3, this source of water might also be considered for agriculture since it would represent an annual expenditure of $1/hectare for year-round irrigation. Another proposal for the use of ice from the Antarctic in order to produce water is to bring it on flexible barges, coated with black heat-absorbent materials so that ice would melt by the time it reaches its destination.

Many other technology-based plans will also emerge as research and development efforts are pursued in industrialized countries. At the International Corn and Wheat Improvement Center in Mexico (CIMMYT) and at Kansas State University in the United States, research work is carried out which may lead in a couple of decades to the production of "superplants...[which might] combine the drought tolerance and disease resistance of barley, the self-fertilizing root system of the soybean and the high yield and food value of wheat" (New York Times 1974). After their visit to China, a group of U.S. scientists reported about backyard factories, each producing a few thousand tons per year of nitrogen fertilizers from coal and water (Rensberger 1974). A UNESCO Delphi survey in 1973 explored the feasibility and usefulness of many other advanced technologies for African development. The results are summarized in the attached tables subdivided into "interesting," "moderately interesting," and "non-interesting" technologies. These results give also estimates for the time needed to implement these technologies and of the type of policy action they would require.

Technologies of Particular Interest to African Countries

Description of the technology	No. of years preceding the probable date of implantation of the technology in question	Type of policy needed for the technology in question			
		Scientific and techno-logical policy		Economic or socio-cultural policy	
		A	B	C	D
Helium filled airship	5-10	xxx	xx	x	
All terrain vehicles	5-10	xxx	xx	x	
Transportation of mineral and agricultural products by pipeline	5-10	xx	xxx	x	
Telecommunications based on the satellite	5-10	xx		x	xxx
Small self contained power sources for use in remote areas	less than 5	xxx	x	xx	
Use of solar energy in air-conditioning	10-25	xxx			
New materials and techniques for road-surfacing	5-10	xxx		xx	
Pulp and paper plants allowing the utilization of mixed deciduous forests	5-10	xxx		xx	
Educational techniques for home use	5-10	xxx		x	xx
Birth control techniques	5-10	xx			xxx
Use of African herbs in pharmaceuticals	5-10	xxx		xx	
Production of leaf protein	10-25	xxx		xx	
Chlorella for milk substitute	5-25	xxx		xx	
Synthetic sources of nitrogen	5-10	x		xxx	
Glandless cotton seed varieties suitable for Africa	5-10	xxx	xx		
Storage facilities for peanut products which prevent the development of alfatoxin	5-10	xxx		xx	
Developed No. 2 opaque corn suitable for Africa	5-10	xxx		xx	
Genetic manipulation to control diseases and produce selective plant varieties	5-10	xx		xxx	
Non-polluting pesticides	10-25	xxx		xx	

Technologies of Moderate Interest to African Countries

Description of the technology	No. of years preceding the probable date of implantation of the technology in question	Type of policy needed for the technology in question			
		Scientific and techno-logical policy		Economic or socio-cultural policy	
		A	B	C	D
Hovercraft	5-10	xx		xxx	
Desalination with solar energy	10-25	xxx		xx	
Improved methods for low grade ores	10-25	xx		xxx	
Iron ore reduction process by natural gas	10-25	xx		xxx	
Self-propelled hole borer for mining and hydrological use	10-25	xx		xxx	
Automated teaching techniques	10-25	x		xx	xxx
Use of rice husks, bamboe and other materials in the building trade	5-10	x		xxx	
Edible proteins from petroleum	10-25	xxx		xx	
Food preservation by freeze drying	5-10	x		xxx	
Production of nitrogenous or compound fertilizers from by-products of oil refineries	10-25	x		xxx	

Technologies of Little or No Interest to African Countries

Description of the technology	No. of years preceding the probable date of implantation of the technology in question	Type of policy needed for the technology in question			
		Scientific and techno-logical policy		Economic or socio-cultural policy	
		A	B	C	D
Air cushion vehicles	5-10	xx		xxx	
The vertical take-off and landing system	5-10	xx		xxx	
Laser links	10-25	xx		xxx	
Microwave links	5-10	xx		xxx	
New techniques for harnessing the wind	5-10	xx		xxx	
Solar energy devices	10-25	xxx		xx	
Desalination of sea-water with nuclear energy	10-25	xx		xxx	
Thermo-nuclear power system	more than 25	xx		xxx	
Fuel cells	10-25	xxx		xx	
Desalination with permeable membranes	10-25	xx		xxx	
Helicopter transported operating theatres	10-25	xx		xxx	
Environmental controlled communities	10-25/more than 25	xxx		xx	
Nitrogen fixation by enzymes	more than 25	xxx		xx	
Weather control over large areas, artificial rainfalls	more than 25	xx		xxx	
"Nuplex"	more than 25	xx		xxx	

A: Science policy relating to a particular technology.
B: Science policy furthering general scientific development.
C: Economic development policy.
D: Socio-cultural development policy.
xxx: Policy to be followed of crucial importance.
xx: Policy to be followed of considerable importance.
x: Policy to be followed of some importance.

Source: UNESCO "Results of a UNESCO Delphi Survey on Technologically Feasible Futures for Africa" SC/CASTAFRICA/Ref 2, Dec. 1973.

7. CONCLUSIONS: TECHNOLOGICAL PROGRESS

Development based on the application of advanced technologies generally requires more capital investment than the progressive modernization and expansion of existing production systems. Our basic assumptions are that large-scale development projects based on the application of advanced technologies generally have very little direct impact on the socio-economic development of a region. They may generally be viewed as foreign enclaves. However, they have the advantage of being non-sensitive to droughts. Therefore, they may be conceived as stop gap programs which assist for the medium term, and which provide a cushion in periods of sustained drought. They do not, however, act as an effective catalyst for promoting further development in the region.

Among the technology-based development schemes described in this section of the report, it would appear that the most interesting are the following four:

(1) The first two phases of what was referred to as the Ubangui-Chari scheme. This would include development of a capability for long-term planning for water management in the Lake Chad Basin by strengthening the Lake Chad Basin Commission. Channels and levees would allow the irrigation of 400,000 hectares in average years and over 70,000 hectares under drought conditions. Simultaneously techniques would be developed to reduce evaporation losses. Over a fifteen-year period the Logone-Chari waters could be progressively supplemented by waters from the Ubangui.

(2) The scheme described as the west African waterways would also have a high priority. This scheme would be directed primarily to the regularization of the Senegal and Niger rivers. Support would be given to the O.M.V.S., the Liptako-Gourma Authority, and the Niger River Commission to coordinate the development of those two rivers

with agriculture and urban growth. The construction of the Manantali Dam would be viewed as the first step to providing water for the irrigation of up to 900,000 hectares, power for industrial complexes and year-round navigability over long stretches of these two rivers.

(3) The conversion of grass and agricultural wastes to produce methane would also be a feasible and useful technological development. This technique is already proven at the artisanal level. Commercial production of methane would put to a use a large potential source of energy. This production would have an important ecological impact in halting the process of desertification, and a significant economic impact in reducing the balance of trade problems. Other utilizations of grasses such as compacting them for use as fuels or plowing them back into the soil should be evaluated.

(4) The opening of new areas through disease eradication programs would provide a significant, although less drastic, contribution to the development of the region. Such programs have already been started with the assistance of the World Health Organization.

Some crude calculations provide an idea of the magnitude of capital which might be needed in the Sahel-Sudan region if some of the large schemes described above were to be implemented. We will assume that agriculture production must increase to keep up with the increase in population, that is at an annual growth rate of 2.2 percent. We will also assume that all the present capital resources of the region would be applied to industrial development, urban growth and basic needs for infrastructure, while additional foreign capital would be used to provide new food production facilities.

The capital investment needed varies a great deal depending on the particular project being considered. The plan suggested by Revelle (1974) would require about $1,500 per hectare for the year-round irrigation of about 150,000 hectares. The Manantali dam would cost about

$80 million and would irrigate 300,000 hectares. However, when the cost of land development is included, the complete plan would require about $2,500/hectare. The Ubangui-Chari plan would cost about $1,200/hectare for year-round drought-proofed irrigation. Land development costs may add another $1,500/hectare. In Niger, cost estimates for irrigation projects have been quoted at $4,000/hectare. A Nuplex is projected by different sources to require a capital investment of $200 for the production of the equivalent of food for one person, which may, however, become as high as $1,000 per capita under our set of assumptions. Production of meat in areas infested by tsetse flies may require investments of about $50 per capita for their eradication. The onchocerciasis program in Upper Volta averages $165 per capita. Combining these estimates, we may assume that the production of the equivalent of food for an additional person requires capital investments in the order of $100 to $500. We will assume that a capital investment of $200 per capita will prevail for the first increment of 5 million people, i.e. for about 20 years, while $300 per capita will be needed from then on.

Therefore, a typical investment of $200 provides the equivalent of the required food per capita (about $50 per year) including a $10 return on the capital. And, the additional annual investments which would be needed under these conditions would be about $110 million per year in the first few years. Depending on the interest rates charged, local savings would then have a higher rate of growth, after a few years, and would decrease the annual requirement for foreign capital. This calculation is only intended to give an idea of the magnitude of additional foreign investments which would be needed under this set of assumptions. However, the capital costs estimations for these temporary stopgaps should be complemented by an evaluation of the additional long-term investments required to achieve ecologic balance in the region and to develop the education and health systems and provide for other areas of human re-

source development. Indeed, technology cannot merely be introduced into a region as a marketable package. True technological progress requires time. It has been argued (Fusfeld 1973) that technological progress is largely the result of a learning process and thus is a function of the number of repetitions of the needed tasks (or total production size). Figure I.7-1 shows a measure of technology (productivity) plotted against cumulative production. In this plot, the slopes are measures of the rate of learning, or of the technological progress. The technology of rice production in Japan shows a sharp change in its progress rate in 1854 when Japan experienced a profound social change (Fusfeld 1973). Figure I.7-1 also shows that technological progress in rice production in Niger is slower than that of modern Japan, while peanut productivity in Senegal is practically at a standstill. Therefore, it is less important to find out <u>which</u> technology is useful than to understand <u>how</u> to accelerate true technological progress. How did the socio-economic changes in the Japan of 1860 improve the rate of technological progress? How might increased rates of progress be achieved in Niger, or Senegal, or other Sahel-Sudan countries? The following two section ("Choices of Technology: Forces Affecting Choice and the Decision Process" and "Education and Institutional Development") address the "how" question. They argue for "broad-based" technologies, i.e. technological development having significant social impacts, and for the development of institutional capacity so that new technology becomes easier to assimilate and becomes directly linked to social and economic development of the region.

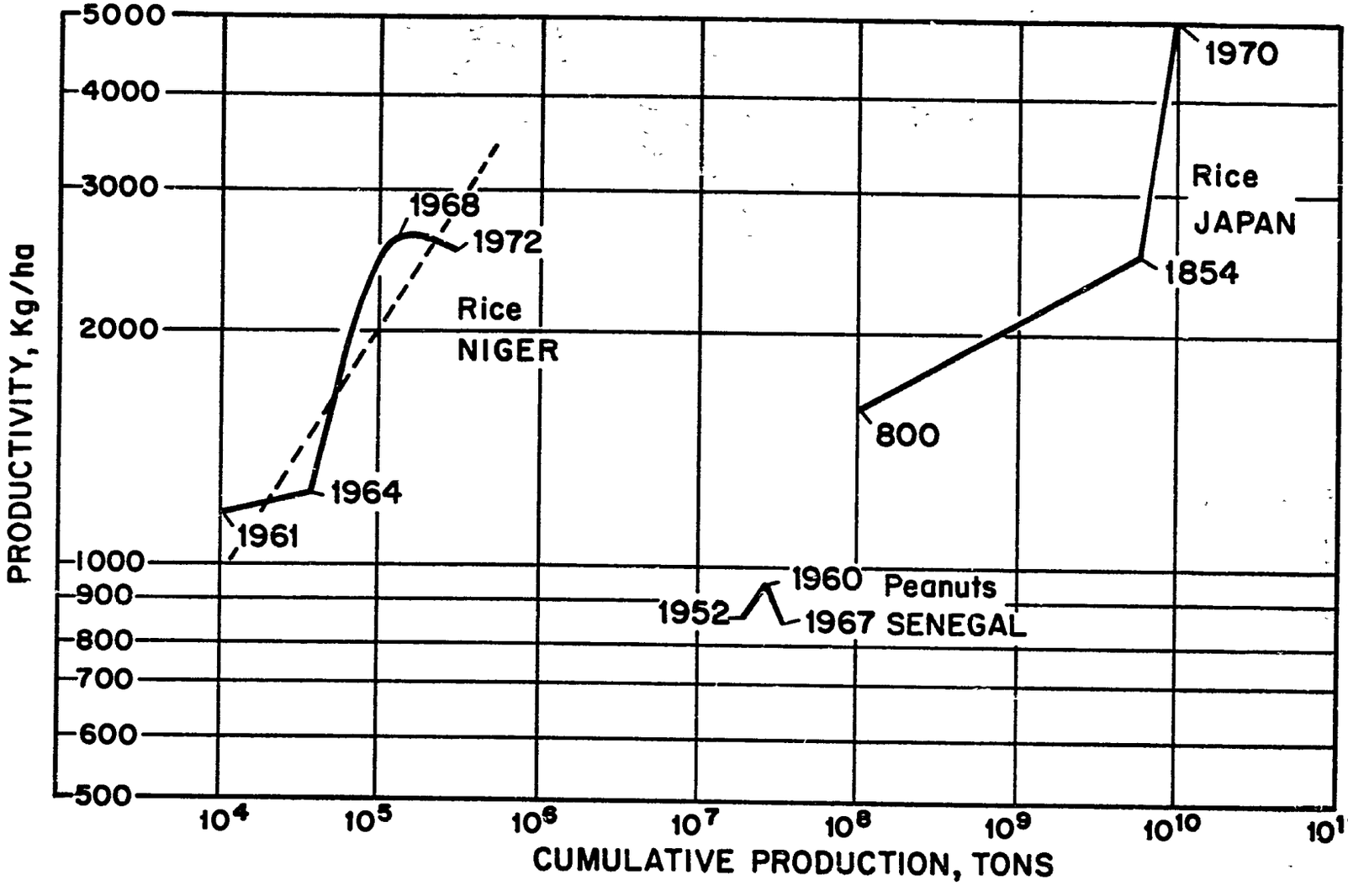

FIGURE I.7-1 Illustration of the Technological Progress Function

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Part II

CHOICE OF TECHNOLOGY:
FORCES AFFECTING CHOICE AND THE DECISION PROCESS

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Joseph E. Soussou

K. Nagaraja Rao

1. INTRODUCTION

1.1 Scope

Debates about the types of technologies needed for development ultimately return to the question of technological choice and the capacity of nations and their institutions to make choices of appropriate technologies. It is well known that technological choices whether made locally or by donor agencies and foreign investors, tend to have far reaching effects on the rates of development and in the severity of the consequences. In many cases, it has been argued that developing countries have broader choice of technology, since the direction of development has not yet been set and therefore, some flexibility still exists. For example, it is contended that since there are only a few urban centers in the Sahel-Sudan region, decisions on urbanization patterns may be easier (faster and less costly) to implement than in other industrialized areas. Similarly, choices in other sectors such as education, health, and transportation can be made with relative flexibility compared with those in more developed countries. If the U.S. is to shift to a policy emphasizing mass transportation to replace the private automobile, far reaching implications will ensue when compared with a similar decision by the government of Mali or Mauritania.

Some development economists would also argue that fundamentally there is no real choice with respect to technology for the LDC's (Eckaus 1973). Technology developed in industrialized countries has been the result of several levels of optimization, influenced by free market forces. Despite the resource differentials between industrialized and developing countries, the existing technologies, having been tested and "debugged," are equally well suited and are generally the ones available for use in developing countries. The bulk of those arguments is directed towards the manufacturing industries, however. While these arguments may have

merit, they seem to miss the importance of the following characteristics of technological development:

(1) Development is essentially a dynamic process. Therefore while labor-intensive technologies are sought in certain localities at certain times, localized and temporal labor shortages can occur even in most labor abundant regions. When one evaluates a number of production sectors in the Sahel-Sudan region such as agriculture and transportation, and compares them with corresponding ones in the U.S. in the late 1800s and early 1900s, one can generally state that they exhibit similar features. Figure II.1-1 shows a comparison of corresponding energy utilization patterns in food production between the U.S. and a number of developing countries. A conclusion from this comparison may be that the Sahel-Sudan countries must follow a course of action similar to the one pursued by the U.S. to develop their agricultural resources and industrial capabilities. Given their resource limitations, however, it may take at least 100 to 150 years to reach an equivalent level of development. By then, the U.S. perhaps would be in a different category of development altogether. But while the U.S. and other advanced countries have been the primary producers of technology, the developing countries can draw upon that experience and hopefully short-circuit certain developmental paths. The question which still must be addressed is: Given that certain technologies are "appropriate" at one time, are they still appropriate at a later stage of development when both local and world conditions have changed so dramatically and expectation of people have also changed? While it can be correctly argued that the development of the transistor was hardly motivated by labor-saving or even capital-saving goals the further development of integrated circuits was in part motivated by labor-saving objectives. Similarly, the development of automated assembly plants pursuant to the development of the internal combustion engine was in fact a labor-saving, capital-intensive

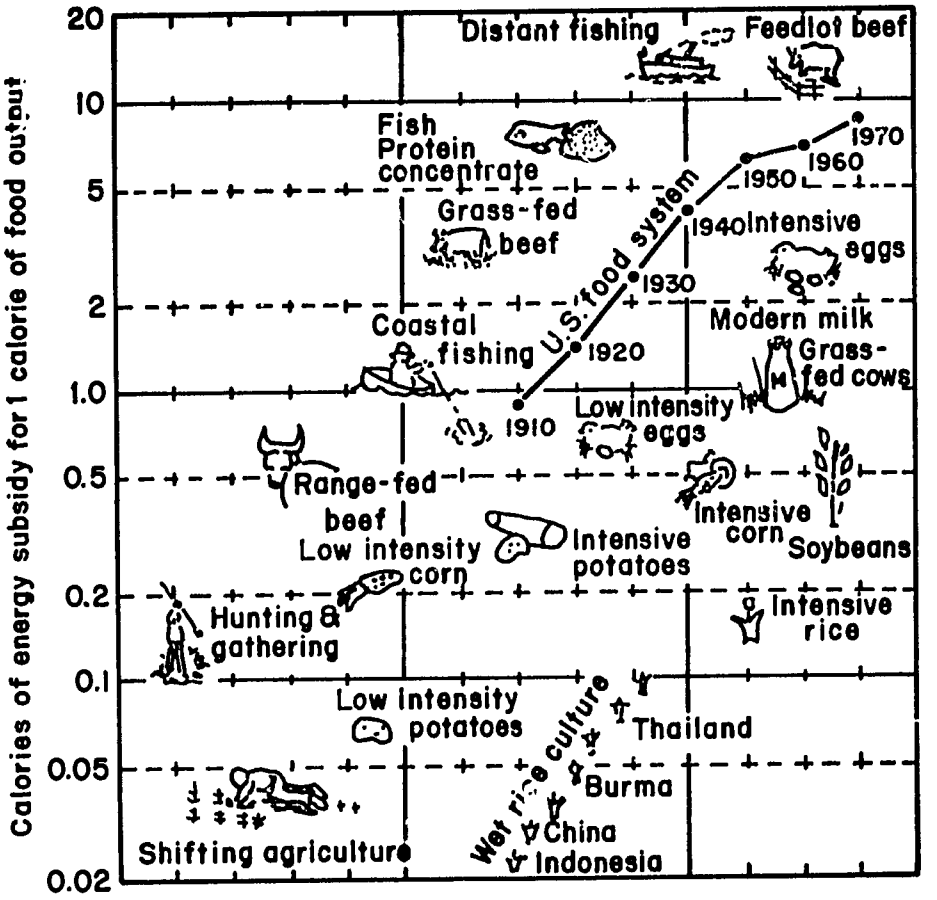

FIGURE II.1-1 Energy Used in Food Systems

From Steinhart and Steinhart (1974) Copyright 1974, American Association for the Advancement of Science.

scheme. In short, the dynamic nature of economic development imposes considerations beyond the static and linear lines of reasoning insofar as the choice of technology is concerned.

(2) A partial answer to the above questions may be provided at least in a qualitative manner through a more comprehensive view of development to include in addition to growth criteria, criteria related to distributive justice, quality of life, and criteria that enhance opportunities for choice for the individual in that society. A five percent growth in the GNP of Mali can result from the change from head-basket or burrow transport mode into animal and tractor powered carts. A corresponding growth in an industrialized country may be the result of use of integrated circuits, automated assembly plants, and computerized information and communication systems. The forms that these developments take and the rates at which they occur have profound implications for the distribution of wealth and social benefits as well as on the social organization for production and the reduction of regional disparities in development.

1.2 Forces Affecting the Choice of Technology

To fully understand the dimensions of technological choice and to provide a meaningful framework for the development of criteria for that choice, it is essential to understand the major forces affecting technological choices. Three types of forces whose interaction shapes technological choice at various decision-making levels are described below:

(1) Political forces: In the Sahel-Sudan region decision making is highly centralized at the national level. In some important fields of action, decision making is centralized in certain regional bodies. Therefore, it would seem that unified policy decisions on questions such as those having to do with labor-intensive approaches in agricultural or construction activities can effectively be provided. But this apparent advantage is often illusory. The dependency on foreign aid and investments

impose serious limitations on freedom of choice. Presently, most foreign aid is provided in the form of capital goods, short-term food and medical supplies, and limited technical advice. The differing philosophies and operating procedures of donors and lack of coordination among them, limit or confound the choices available. Shortages of experienced manpower and institutional inefficiencies further reduce the capacity for choice.

(2) Social forces: The ultimate objective of technology is to increase social welfare through increased productivity and better communication, education, medical care, and other social services. Technology creates new social forces and often these forces shape technological requirements. The lack of high level manpower and institutional capabilities to make rational choices among alternatives available is a serious handicap of the Sahel countries. We will later argue that this element constitutes the major, and singularly most important factor in the choice of technology. Other social forces which may affect the decision-making process include (a) population patterns and pressures resulting from the differing life styles of nomadic, rural, and urban people; (b) language and cultural differences within each country, and across national boundaries, affecting the nature of technology used in communications and educational systems; and (c) birth rates and their effects on medical technologies related to population control and health care delivery.

(3) Economic forces: The traditional economic goals of efficient resource allocation, increased foreign exchange earnings, and growth of GNP dictate national policies on choice of technology. The relative scarcities and costs of factors of production determine the general directions of labor-capital proportions in various sectors of production. Goals related to foreign exchange reduction lead to development of import substitution in the manufacturing sectors. Increases in GNP are achieved by

emphasizing one sector whose contribution to the total economic output is greatest.

There is generally a complex interplay among the economic, social, and political forces in a given country. For instance, the choice of labor-intensive technologies might be motivated by social or political factors, even though they may not be economically feasible. Conversely, the choice of labor-intensity on economic grounds may not be in total harmony with social motives, such as population movement, urbanization, and so forth.

What is evident is that none of these forces can be continuously overriding, and conscious efforts must be made to examine their interactions and impacts. In the next section, an attempt is made to develop a set of relatively subjective criteria which can be used as a guide for technological choice.

2. SOME CRITERIA FOR CHOICE OF TECHNOLOGY

Central to the discussion of choice of technology, are questions of level and purpose of selection. A decision at the national level to emphasize labor-intensity in the construction industry for example may derive from a set of criteria and national goals distinct from those on a project level. The first set, referred to as systems criteria, is derived from a central philosophical orientation, while the second is based on considerations of economic efficiency, applicable management techniques, and local constraints. Although the two must somehow be compatible to ensure maximum coordination and efficient distribution of social benefits on the broadest national level, different weights are given to each. In this section the systems criteria are presented from the perspective of broad national development, while the second set of criteria are presented in the form of typology or characterization of component technologies on project or sectoral levels.

2.1 Systems Criteria

The following set of criteria for choice of technology are derived from the viewpoint that the development process can be interpreted as: (1) an accumulative process of physical resources, such as skills, materials, and infrastructure; (2) as a transformation process of the macrosocial system expressed in terms of the overall characteristics of the system and its institutions; (3) as a dialectic process in which not only the degree but the kind and patterns of change in the social organization of production are considered (Vietovisz 1973).

Each of these aspects of development can be measured by three indices of the system: (1) differentiation or level of disaggregation--such as the number of distinct industries, infrastructure, and resources--that the system itself distinguishes; (2) integration which denotes the ability of the system's components to act in a complementary fashion; and

(3) linkages which measure the degree of connectedness of the system with the outside world (R. Young 1970; F. Young 1968).

The first two indices relate to the ability of the countries to "absorb" and develop technological innovations, while the third refers to the channels through which technology can be "transferred" and products exchanged.

This multi-faceted view of development, and its respective composite measures lead to a corresponding sequence of actions for achieving developmental goals. These actions reflect different emphases in the question of choice of technology. This can be briefly stated as follows:

(1) In the accumulative aspect of development, the emphasis is placed on design of resource allocation and organization of the production system. The choice of technology is focused on the efficient utilization of resources with the appropriate choice of capital and labor intensities. World price structure affects these decisions significantly, especially when it relates to choices on export orientation and import substitution (Little et al. 1972a, 1972b).

(2) The view of macrosocial change places a focus on the local adaptation of technology, on the building of institutions to increase the differentiation process underlying development, and on integration of institutions serving separate functions, such as academic institutions and local enterprises. These relate to the correspondence of various technological processes and the institutions responsible for their development or implementation. The choice between technological alternatives will then center on which alternative contributes most to strengthening these macrosocial functions, bringing a structural change in the organization of production.

(3) The dialectic aspect of development implies the role of technological alternatives in contributing to qualitative changes in the social organization of production, and in perpetuating or reducing external

dependency. Technological interventions at different levels generally have many process values, including the creation of an ethos of development. This raises questions about value structures, and therefore decisions on technological choice must incorporate rates of change of the social system and its values.

In the context of the Sahel-Sudan region, decisions on choice of technology centered on changes in institutional structures and on corresponding policies are likely to yield positive benefits in the long run. Institutional development considerations are addressed separately in Part III of this study.

In what follows, the criteria for technological choices are listed in the form of propositions outlining their relative separability and otherwise interdependence. These are not necessarily exhaustive nor are they mutually exclusive. They suggest the type of norms that must be recognized before decisions are made on the selection of technology.

(1) Contribution of technology to institutional development: In a broad sense the technological innovation must be geared to fostering institutions, stimulating skills, and supporting derived functions. An alternative technology should be prefered if it possessed an inherent dynamic that leads to a crystallization of training and innovation, leading to local adaptation of foreign technology and possible production of local versions. Technological choice should be based on the extent to which an alternative contributes to integration with other technologies, through a creative interaction between research institutions and production enterprises.

(2) Contribution to structural changes: The utilization of technology should contribute to societal integration, where the benefits derived from the use of technology are diffused over a large part of the population, striking a balance between urban and rural areas. Technology should not be used to increase disparities between urban centers and rural areas

which might lead to a unidirectional flow of population into urban centers.

(3) Contribution to autonomy: A technological alternative must lead in the direction of autonomy rather than the perpetuation of dependency on foreign technology or assistance. This applies both for the technology itself as well as for its input requirements of skills and management, materials, and energy.

(4) Relevance and implementability: The technology used must be compatible with available manpower and management capabilities at the national, regional, and local levels. Therefore, the ability of technology to draw upon local resources and capabilities, the operational requirements, its sophistication and its compatibility with the prevailing environmental conditions, are important considerations when the choice is made.

(5) Economic factors: Efficiency, timing, cost-benefit trade-offs, foreign exchange, capital requirements, are all familiar factors in project evaluation which are quite important, and have been extensively discussed.

2.2 Characterization of Component Technologies--A Typology

We will introduce a certain number of concepts or definitions in order to characterize technologies: type, sophistication, scale and indigenousness. This classification defines a matrix summarizing the principal endogenous characteristics of a technology of interest to a planner. These four characteristics are endogenous in the sense that they are functions of the technology itself. This classification is useful but arbitrary, as even the endogenous characteristics depend to some extent upon the frame of reference. For instance what may have been a common technique of extracting salt from vegetation in the early nineteenth century in central Africa, may be considered now as a complex and sophisticated technique (De Gregori 1969).

2.2.1 Type: Type is defined simply as the economic sector

to which the technology contributes. There may often be several such sectors in which case it would be classified under the principal one.

2.2.2 Sophistication or relevance: The quantification of this concept may be difficult and probably unnecessary in this context. What is sophisticated within one frame or reference may be elementary in another. As a general rule, however, sophistication refers to complexity of manufacturing or of use, or both. For example, transistor radios are less sophisticated than computers despite the fact that transistor technology enters into their manufacturing. Relevance refers principally to available skills, infrastructure and institutional capacity. It does not necessarily imply economic feasibility. For convenience of discussion three levels of sophistication are recognized:

(1) "Grass-roots" or "people" technologies--These are the very simple technical improvements that might make the daily life of the people a little better by helping them overcome drudgery, conserve their meager resources of food and water, improve sanitary conditions and reduce susceptibility to disease. These are also likely to be the techniques that are energy-conserving, ecologically least harmful and most attuned to the cultural practices of the people.

Technologies in this category are "appropriate" also from the point of view of the level of investment required. Individual families most often could afford to acquire these technologies; or community organizations, such as supply and service cooperatives, could with some technical assistance and low levels of financial assistance be enabled to purchase and use these technologies. If the activity involves the production of articles in the home for selling in local markets, the cooperative could also provide marketing services.

Technologies at this level of complexity are also available for such needs as mechanization of building construction, manual methods of dehairing of hides, threshing of fibers, manual pressing of oils, purification

of water for drinking, preparation of ponds for stocking fish, and a variety of other occupational needs in the agricultural and artisanal areas of activity or the mere simplification of the job of acquiring food and water, improving shelter and maintaining good health.

A list of technologies that would meet these criteria are illustrated by the list of village level technologies available from VITA (Volunteers for International Technical Assistance, Maryland). Similar lists are also available from the Intermediate Technology Group of Great Britain. VITA also provides technical drawings and detailed instructions in the use of some of the technologies.

Although it is a relatively simple matter to develop lists of such "grass-roots" technologies, their successful introduction into the community is by no means simple. As community development efforts in several parts of the world have revealed, demonstration, patient and sympathetic assistance and follow-up are needed before communities are ready to discard old ways and adopt new ones. The real benefits of the new technique over the previous one have to be shown before the practice spreads. We can assume that the attitude of Sahelian people will be no different from other societies and because educational services have not reached vast areas of this region, the introduction of change in the daily habits and practices is likely to be even harder in this region than in other parts of west Africa.

(2) Intermediate technologies--It is possible to envision a second level of technologies that could be introduced in animal production units, in the indigenous small and medium scale industries that process agricultural and livestock products or make other consumer goods for the local markets. These technologies are slightly more sophisticated than the technologies described above. They also may require larger investments, better organization and management, and in the Sahel-Sudan countries, where banking and credit institutions are at a very early stage of

development, a greater involvement of the government in providing these services. Establishment of new or strengthening of existing institutions of banking and credit, supply and procurement process, engineering and maintenance organizations constitutes a necessary step before a major program of assistance to the small and medium enterprises is provided. Because of the scarcity of local capital and entrepreneurs in the region, the governments may have to experiment with a variety of public/private, foreign/local, national/regional participation systems in the modernization of the small and medium industrial and agricultural enterprises in the region.

This level of technology would introduce mechanization into the operations in industry or agriculture with a view to improving the quality of the products, increasing productivity or reducing cost of production (through better packaging, freezing, drying, and generally through achievement of economies of scale). The question of whether these technologies should be labor-intensive or capital-intensive must be addressed separately. The disadvantageously high prices for labor and lack of local technical skills and management capacity are likely to weigh heavily in favor of the selection of capital-intensive technologies. Whether such powerful market forces can be moderated by deliberate policies favoring the selection of labor-intensive technologies is an open question--it will depend very much on the capacity of local departments of industry, trade and planning to analyze complex investment questions and their strength in negotiating terms favorable to the Sahel-Sudan region for reducing unemployment and for building local technical and management capacity. Unfortunately, the drought has further deepened a dependency of these countries on external factors and agencies and has reduced their freedom considerably to make the choices in technology as in many other development issues.

Under this level of technological sophistication or complexity, a subsidiary consideration is the kinds of "public" technologies that may

be appropriate for the conditions and needs of the Sahel-Sudan region. Community drinking water storage and purification facilities, rural roads, earth dams for agriculture (including technologies for prevention of seepage and evaporation), rural housing, schools and roads, community food storage facilities (including techniques for rodent control), community education programs especially for women, etc. would require careful consideration of technologies which meet both the ecological and economic criteria described above.

The technologies selected in the "public" sphere are likely to strongly influence the patterns of human settlements and social organization in the region. The infrastructure provided through carefully selected technologies will most likely help in the pulling together of nomadic populations into population centers with two major consequences. It would help relieve the pressure of people and animals on the land and thus make ecological recovery possible. On the other hand, depending on the rate at which this farm to town movement takes place, it is likely to strain the ability of governments to provide the services for rapidly increasing populations in the "growth" centers. Controlling the rate of this movement would be the difficult task of planners and policy-makers. As stated earlier, even countries with longer development experience have had difficulty in managing the rate of rural to urban migrations. If anything, their policies of favoring investment in urban infrastructure have tended to pull people away from rural communities faster than such amenities could be completed in the cities, resulting in the rapid formation of urban ghettos and peripheral shanty towns, a situation that has already developed in some of the towns of the Sahel-Sudan region and along the coast of west Africa (e.g., Lagos).

(3) Sophisticated technologies--A third level of technological sophistication would include those technologies, which at first blush would be dismissed as thoroughly "irrelevant and inappropriate" to the development of the Sahel-Sudan region. But the difference between what

is sophisticated and what is not is becoming less clear. Satellites are being used to map the resources of the earth. For the first time one has some macroviews of soil conditions, river valleys and the possibility of monitoring geological and ecological changes in the region. It took a satellite picture recently to rediscover that controlled use of the land is needed and that simple fencing of a vast acreage results in its ecological regeneration. The feasibility of solar and windmill technology are being reexamined in the United States and elsewhere by government agencies and large corporations. Even the most sophisticated technology becomes appropriate in certain geographical and environmental contexts.

2.2.3 Scale: The concept of scale is related to the potential number of users of a given technology. When technology is applied to the establishment or modification of a production process, scale relates to the size of the production unit or the local market. When it is in the form of consumer products or services scale is concerned with the population to be served. This characteristic is very important since it has major effects on the distribution of income, wealth, education, or services. The concept of scale with respect to production units may be quantified by an ordinal index tied to the number of employees in a factory, or the area of a farm or the size of the herd, etc. In the case of consumer goods and services, the market size and its geographic distribution may be used as the scale index. In the following discussion an arbitrary distinction is drawn to classify technologies according to scale. This distinction is made according to the extent of impact of technology on the population and its effect on geographic distribution of production units and markets.

(1) Broad-base technologies --These are the technologies reaching a relatively large number of users and generally imply a simplicity in either the product itself or its use. For instance, in agriculture the introduction of improved seed varieties, on-farm grain storage facilities, animal power, agriculture wastes for fertilizers, and soil conservation techniques

are considered as broad-based technologies. Similarly plastic sacks, bread based on millet or cassava flour, drying and smoking processes for fish by and large are also broad-based technologies.

Small self-contained power units, community windmills and solar collectors, solar pumps and use of aerial photography for improved land use are also broad-based technologies according to our definition.

(2) Narrow-based technologies--Although this category could often be identified with sophisticated technology, it does not have to be the case. This may be true for most industrial production. However for farming, any technology related to irrigation may be considered as narrow-based because of its geographical limitations. The mining industry, for example, involves also narrow-based technologies because of its geographical confinement, and the limited number of people it employs.

Air transportation is a narrow-based technology, in contrast to bicycles which reach more people. Hydroelectric power plants, or nuclear powered agro-industrial complexes fall also in this category.

2.2.4 Indigenousness: This element measures the degree of adaptation of a given technology to local resources, i.e. capital, labor and physical resources. Thus if labor is relatively more available than capital, the proportion of labor and capital may be used to measure indigenousness. The trend in industrialized countries has been towards a relative increase of capital and a corresponding reduction of labor inputs. Although this is contested by some economists, capital intensity is almost synonymous with modern, advanced and sophisticated technologies. However, a distinction should be made between these concepts. A technology may be sophisticated and labor intensive, as demonstrated by some electronics industries. Under certain conditions, economic forces may be sufficient to weed out the less productive technologies, thus capital or labor intensities would not be directly relevant. The choice of "optimal"

technology may not be very sensitive to the relative abundance of capital or labor. This is not always a realistic assumption, however, since capital is generally a limiting factor in most developing countries. Even if local capital can be raised, hard currencies may not be abundantly available to the government. Under such circumstances, technological choice is directed towards optimizing the use of resources under these constraints.

Indigenousness may also be related to the level of adaptation of a technology to local physical resources. This concept is however less amenable to measurement and further work is needed to quantify it and determine its relevance to technological choice.

In summary the four characteristics described in this section, define a classification system which is rather important to the policy-maker. Policies regarding technological choices may be made within this framework as will be demonstrated later in this part of the report by a scenario of technological development.

3. EVALUATION OF IMPACTS AND CONSEQUENCES OF CHOICE: A METHODOLOGY

3.1 Introduction

Preceeding discussions have spoken to the need for improved methodologies which may make the choice of technologies a more manageable task. Although a typology and a set of criteria have been presented, the problem of choice remains complex. Further work would be needed to integrate the typology and criteria into a systematic analysis. In the meanwhile, heuristic approaches can be effectively used to arrive at informed judgements on technology. In this section, the use of interactive simulation models similar to those used by administrators and planners in the military, waste management, business and other types of planning efforts is discussed. The principal advantages of this approach are that (1) it lends itself to the evaluation of large numbers and varieties of alternatives or scenarios, and (2) it incorporates the subtle issues of decision-making elements of uncertainty and some intangibles which are difficult to account for in an analytical approach. The purpose of these simulation models is to provide additional tools for planners in the Sahel-Sudan region and among donor agencies to analyze implications of technological choices. They can be so constructed as to account for conflicts of interest and other social and political factors to: (1) sharpen the thinking of planners by focusing on issues and tracing out their implications; (2) provide the mechanisms for generating and evaluating new ideas and policies; and (3) account for changes in the system.

The following conditions make the use of interactive simulation models more relevant:

(1) Lack of data makes the task of systematic analysis and planning often difficult.

(2) The forces affecting these countries are very large relative to their economies. A small modification in the world market price of peanuts

or cotton may have a serious impact on the country; a new dam is likely to affect the lives of millions of people. Even a relatively small aid program in the form of food supplies may distort the economy of a country or its neighbors.

(3) Local governments have relatively minor leverage on such factors as world market prices, foreign assistance, and labor migration policies. Under these circumstances it is easy to take a fatalistic attitude: "There are no reasons to work out a serious development plan since there is almost no control on the means to implement it."

(4) The highly centralized government structures and the weak economies lead to government involvement and support for most development projects, whether large or small. Therefore in spite of the limitations under which they operate, the actions of the governments may be more critical than in other areas.

Hence, there is a need to investigate the means by which the leverage on and the local control of some critical factors can be increased. In other words, the question is how to optimize the vital decision-making processes when most of the control rests elsewhere.

3.2 An Interactive Simulation Model for Technological Choices

We have previously argued that the choice of technology cannot be discussed without simultaneously discussing social, economic, and political issues. Therefore, the proposed framework to evaluate technological choices, may also be broadly considered as a framework for the evaluation of socio-economic development alternatives.

This framework provides the means to evaluate several sets of policies: buying technologies at high costs versus developing own specialties at high risks, cooperation with the west African countries on technological policies, governmental support, and intervention, and so on. This framework also provides a medium for discussing and generating

ideas. For example, a series of simulation runs involving advocates of contrasting theories could trace implications of their theories and show their strengths and weaknesses. For instance, group pressures to influence world market prices may be evaluated. Finally, the impact of stochastic variables such as rainfall may be traced out in such a framework, where it is possible to evaluate decisions such as: taking the risk of not preparing for a possible drought and counting on relief aid, versus preparing for the drought and building up the economy at a relatively slow pace.

The proposed interactive simulation model, would in many ways, be similar to a game constructed for planning the long-term development of the State of Maine. This game includes social evaluators, businessmen, and legislators as "players." It is to be published very shortly (Kaminski 1974).

The model can cover a period of, say 30 years, in increments of five years. There would be experts representing each country involved plus representatives for Nigeria and the other coastal countries. Also one or more experts representing foreign interests (foreign assistance, long-term loans, possibility of migration, prices...) can participate. Foreign assistance programs could also be treated as exogenous and uncertain variables.

In addition, sociologists with a good knowledge of the region can help resolve conflicts and evaluate the social impacts of different programs. This set of "social evaluators" would also complement the information not directly obtainable from the simulation models by qualitative or quantitative assessments such as: "This project could not be implemented here in its present form," or "It would take 5 to 10 years to implement this idea of cooperatives."

The participants would decide at the outset of each simulation run on their objectives. A list of possible objectives, or targets can be

drawn. These targets are measured by economic and social variables, and can be changed for different runs. For instance, health may be represented by the number of paramedical personnel, or by the incidence of infant mortality or both. It is preferable to limit the number of factors at the early stages of the development of the model.

The next step is to decide on investments and other policy decisions over the first five years time. The participants could make alliances and negotiate agreements. The methodology for this first part is described as heuristic because it can be done most efficiently by a series of discussions.

Next, an approximate Monte Carlo simulation is used to generate the principal characteristics of rainfall, foreign assistance, and other exogenous variables over the first five years time. This part of the modeling exercise is referred to as stochastic. It may be simulated with throwing of dice, a wheel of fortune, a table of random numbers, or with computer generated random numbers. Actually, present theories suggest that rainfall might be predictable, almost as a deterministic variable (Landsberg 1974). For instance, strong correlations between sunspot activity and rainfall prove at least the partial cyclical character of rainfall.

The last step is implemented by using a single computer simulation model, several computer models, or a multidisciplinary group of specialists. In this step the added infrastructure and resulting production due to the investments and policy decisions are evaluated. Some iterations are needed to ensure the fulfillment of the compatibility conditions and internal consistency of the system. For instance a policy of increased mechanization of agriculture, results in releasing labor. Thus, simultaneous developments in other sectors or population movements should take place. Similarly industrial development could not take place without the availability of energy, water, transportation, or labor. This step

is deterministic in nature, and it uses causal relations supplemented by statistical information and the judgement of the social evaluators. At the end of this step, new decisions are made by each member of the group with respect to investments and other policies.

Figure II.3-1 shows a graphical representation of its structure and flows. The analyses of the results of several runs can be very useful in identifying the differences in perception of and sensitivity to problems by various people. Also it can serve to identify critical factors which are likely to influence the region, and to structure information. Ideas of regional cooperation, political alliances, and pressure groups may be explored. Donors-receivers relations may be reevaluated. Assistance in the form of technology support may be compared with capital loans and/or food aid. The model outputs could force the participants to take a different look at problems than they have been accustomed to within their specialty or within their national boundaries. The dynamics of the model makes it possible to alter or introduce new ideas or alternatives in the middle of the simulation.

3.3 Scenarios of Technological Development

We have stated earlier that it was unlikely that a few miracle technologies could produce the needed impetus for the development of the entire region, but that entire technological-socio-economic development packages related to national and regional goals have to be fashioned.

Part I of this report has presented several major technological ideas and several scenarios of massive technological development of the region. A contrasting, but illustrative scenario, using broad-based technologies is presented below. Our purpose is not only to illustrate the "mix" of technologies of different levels of sophistication for given levels of investment and management capacity, but also to present two distinct alternative scenarios which can be subjected to the interactive simulation

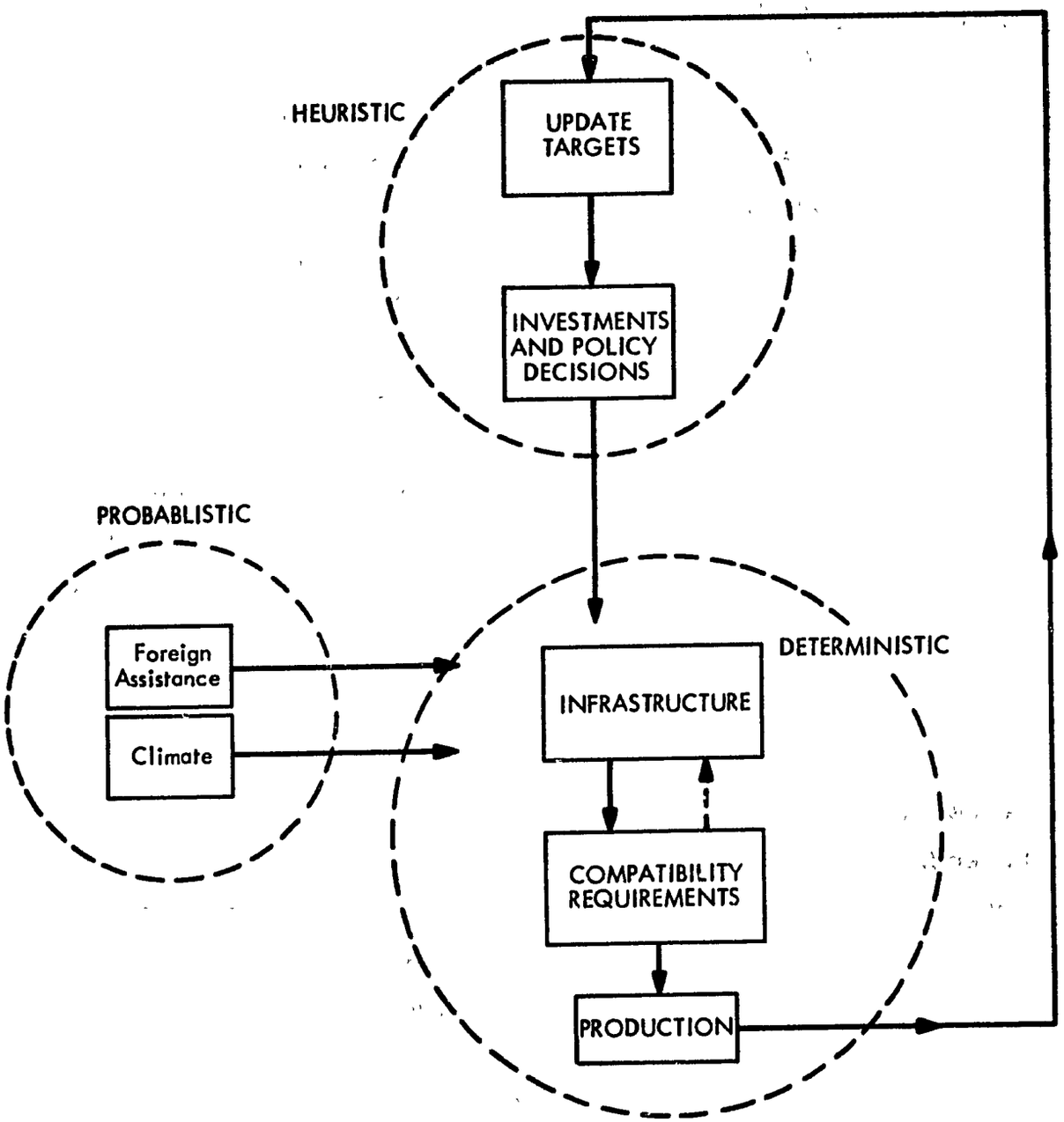

FIGURE II.3-1 Framework of the Interactive Simulation Model for Technological Choice

model type of analysis described in the preceding section.

In a scenario illustrating the use of broad-based technologies, development is achieved principally by the introduction into the present social structure of technologies which are either simple enough to be grasped and applied by large segments of the population, or which are more sophisticated but directly affect large segments of the population (by definition, broad-based technologies). For instance, the introduction of the wheelbarrow or animal power in agriculture is considered as an example of simple technologies, while radios and telephones are sophisticated technologies but are also included in this first scenario because of their impact on large segments of the populations.

The changes envisaged here are large and consist of increasing the skills and capabilities in all the regions and in all of the economic sectors. Therefore, large efforts will be devoted to the agriculture sectors since they encompass the activities of over 85 percent of the population. Improvement of the productivity and quality of life in rural areas are concurrent objectives.

In agriculture, the present patterns of distribution of land and wealth are assumed not to change. This implies a greater emphasis on dry land farming than on irrigation. However, large-scale use of extension agents, radio broadcasts, and other non-formal education programs would absorb a large fraction of the resources. Laws and administrative controls are established to guide farmers and animal raisers to improve practices. Farmers are encouraged to use improved plows, special seeds, and traction animals. Labor intensive techniques and practices are emphasized. This in turn would create local needs which may be largely satisfied by further development of skills of the local population. An example of a labor-intensive practice are the special cropping systems similar to those used in China: "Farmers would, for example, plant rows of wheat, wait for it to sprout and then plant two rows of corn between the

wheat rows. Before the corn was high enough to shade the wheat, the grain would be ripe and harvested. Two months later the corn would be ready. Chinese farmers [said] that this system yielded 40 percent more food than would the same acreage if the two crops were planted separately" (Rensberger 1974). Improved seed production would be done locally and extension agents would also be trained locally. Other improvements include the introduction of grain grinders and threshing machines. Other broad-based technologies that would be used are on-farm plastic film storage facilities and hand operated presses.

Mechanisms and incentives for a more efficient livestock operation would be introduced. Poultry and pigs would be added to the current stock of domestic animals along with the associated technologies such as simple incubators and brooders.

The use of water resources would be improved by the introduction of simple techniques for well drilling. However, this would be accompanied by educational programs to increase awareness of the finiteness of water resources. Water lifting practices would involve the use of siphons for irrigation of low lands, as well as hand pumps and bicycle powered pumps. A whole variety of pump designs would be evaluated in order to introduce the models best adapted to the region and which could be manufactured locally (A.I.D. is financing the development of a low maintenance pump at the Batelle Institute, and its use should also be given consideration). Other improvements would be small earth dams and other water catchment schemes.

In the area of health practices, improved wells, i.e. wells with pumps would alone represent a great improvement in most of the cases. Simple water purification techniques such as filters, solar stills, boilers, etc. would be encouraged. Fly and rat traps are also simple devices which can be manufactured locally. Soap making equipment, septic tanks, and bioconversion of wastes are other broad-based technologies that would

be used. Bioconversion of wastes is a widely used practice in small farms in Taiwan to produce methane gas and sterile fertilizers.

At the community level in villages, the introduction of solar energy and/or wind energy would provide major improvements in the quality of life in rural areas and lead to increased productivity. Such energy sources would operate the village pumps, provide energy for cooking, and the conservation of foods. (Presently over one-third of the dried fish is wasted.) They would also increase the possibilities of trade in food: if milk and meat are refrigerated they may be produced in enough quantities to support local exchanges. Power would be used to make ice, and power radios or TVs. Farms would produce methane and fertilizers from grasses and agricultural wastes, as described in Annex 9 of this report ("Energy and Mineral Resources"). Also "backyard factories" would produce nitrogen fertilizer from inorganic materials such as coal, which is usually found in small deposits.

In the industrial sector, broad-based technologies would improve the quality and quantity of present craftmanship. For example the CINVA-Ram brick press may improve the quality of bricks used in construction. Blacksmiths are presently very skilled at using scrap to produce mattress springs, farm tools, etc. These skills could be used to further expand small scrap industry to provide the agricultural tools needed for the modernization of agriculture.

Productivity increases would require techniques such as fence making machines, welders, forges and drill presses. Other small industries such as woodworking and carpentry would be promoted. The important weaving industry may be improved by better looms and dyes, and presses to produce prints. Other small industries such as food processing may also be improved through the introduction of broad-based technologies.

Transportation development would involve a greater use of locally produced bicycles and modified bicycles, carts, and wheelbarrows, as well

as maintenance of existing roads, and development of feeder roads. Regularization of the rivers, does not detract from this general development philosophy, although it would require sophisticated technologies and large capital investments. It does promote internal trade and exchanges. The use of locally made boats would be encouraged.

Education would emphasize literacy, and extension agents would use local languages. No major change of language would be imposed. Improvement of administrative efficiency of rural institutions would be given priority. Cooperatives would be reinforced, local managerial talents developed, and the spirit of self-reliance and local responsibilities would be supported at all levels of government. In the economic area, credit institutions would provide channels for personal savings and subsidies in the form of low interest long-term loans for agricultural tools, small businesses and industries and wide dissemination of solar or wind power generators and other devices requiring high initial investment.

It is clear from the foregoing analysis and illustrative scenarios that for the progressive assimilation of technology by the countries of the region, the capacity of indigenous institutions and their leaders to make technological choices should be significantly improved. The role of education in this process and questions related to the development of institutional infrastructure in science and technology are discussed in Part III.

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Part III

EDUCATION AND INSTITUTIONAL DEVELOPMENT

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1. INTRODUCTION

Throughout the previous chapters the central importance of indigenous institutions for educational, scientific and technological development of the Sahel has been repeatedly stressed. In the virtual absence of institutions of higher education and a rudimentary public educational system serving only a small percentage of the population, institutional development to propagate technology in the Sahel poses a number of challenges.

Without a country-by-country survey, it is difficult to identify existing institutions and evaluate their capacity to undertake the burdens of a development program, even assuming that large scale external aid will be available for projects in specialized sectors served by these institutions. The brief examination below of the educational sector will reveal the serious deficiencies in the public education system which must be corrected if it is to yield trained manpower for other development sectors.

2. THE FORMAL EDUCATIONAL SYSTEM

The educational systems of the six countries in the region exhibit the classic characteristics of educational underdevelopment: low participation, high drop-out and repetition rates, high cost, and disjunction with the needs of development. While the countries of the region are devoting 15 to 28 percent of the national budget for education (and development agencies are agumenting this investment through loans and grants), the return on this investment is extremely low. In 1970, only about 14.5 percent of all children ages 6 to 14 were actually in primary school and only about 5 percent of all children in the age group 15-20 were enrolled in secondary schools in the countries of the Sahel (United Nations 1972). (See Tables III.2-1 and III.2-2.) The latest information available on the educational systems of Chad, Mali, Niger, and Upper Volta are included in papers prepared for a UNESCO-sponsored meeting of the ministers of education of the twenty-five least developed countries (UNESCO 1974c).

The transposition of the cultural traditions of the French educational system and the high premium placed on the learning of the French language are blamed for the present lack of relevance of Sahelian educational systems to the needs of development. These factors also impede the rapid development of truly national educational systems. The very high proportion of expatriate French and other nationals serving as teachers, administrators, and researchers in the educational, governmental, and development institutions tend to perpetuate a dependency on external resources, ideas, and institutions. Differentiated schools and curricula for the foreign residents of Africa to prepare them for administrative and leadership positions and a separate track for Africans to prepare them for a variety of occupational roles in society was a distinct feature of French colonial educational policy. One useful by-product of that policy, however, is the present availability of a variety of formal

TABLE III.2-1

Budget Invested in Education as Percentage of National Budget of four Countries of Sahel

Chad	1971	15.00
Mali	1971	26.80
Niger	1971	17.60
Upper Volta	1971	22.12%

TABLE III. 2-2

Percentage of School Age Population Actually in School at Elementary and Secondary Levels and by Country

Country	School Level	Year	Total Pop.	Primary (Pop. 6-14) Secondary (Pop. 15-19)	Percent of Pop.	Number children in School	Percent of age group in School
Chad	Primary	1960	3,027,600	753,700	24.9	50,000	6.6
		1970	3,600,000	943,200	26.2	180,000	19.0
	Secondary	1960	3,027,600	278,500	9.2	2,000	0.7
		1970	3,600,000	378,000	10.5	9,000	2.4
Niger	Primary	1960	3,090,150	781,800	25.3	26,000	3.3
		1970	4,050,000	1,061,100	26.2	102,000	9.6
	Secondary	1960	3,090,150	281,200	9.1	1,400	0.5
		1970	4,050,000	425,300	10.5	6,500	1.5
Mali	Primary	1960	4,119,800	1,025,900	24.9	60,000	5.8
		1970	5,022,000	1,315,800	26.2	190,000	14.4
	Secondary	1960	4,119,797	378,900	9.2	6,000	1.6
		1970	5,022,000	527,300	10.5	25,000	4.7
Mauritania	Primary	1960	837,000	209,200	25.0	11,000	5.2
		1970	1,020,000	268,300	26.3	30,000	11.1
	Secondary	1960	837,000	761,700	9.1	600	0.078
		1970	1,020,000	106,000	10.4	3,000	2.8

(Continued)

TABLE III. 2-2 (continued)

Senegal	Primary	1960	3,004,000	748,000	24.9	128,000	17.1
		1970	3,755,300	983,800	26.2	282,000	28.6
	Secondary	1960	3,004,200	273,400	9.1	11,000	4.0
		1970	3,755,300	394,300	10.5	56,000	14.2
Upper Volta	Primary	1960	4,146,000	1,036,800	24.9	40,000	3.8
		1970	5,076,000	1,329,900	26.2	126,000	9.5
	Secondary	1960	4,146,000	380,000	9.1	2,600	0.68
		1970	5,078,000	533,000	10.5	11,900	2.2

and non-formal education and training programs at the elementary and secondary levels in several urban and rural occupational specialties.

As can be seen from papers presented before a recent UNESCO meeting (UNESCO 1974c) on educational problems in Chad, Mali, Niger, and Upper Volta, between 40 and 50 percent of the school teachers in these countries are expatriate French or members of other nationalities working in bilateral technical assistance programs. Student enrollment in these programs is relatively small, and the number that actually graduates is even smaller. The overall picture is one of low internal efficiency. For example, in Mali the average repetition rate in the first six grades of education was observed in 1970 to be between 23 and 37 percent. This means that if the statistics hold over a long time period, only about 15 percent of the entering first grade students will go to the secondary stage six years later. The following secondary stage of education experiences similar problems of repetition and dropouts, where it was observed that less than 25 percent of the entering class finishes the third year of secondary school in three years time. This means that only 3 to 5 percent of the entering first grade students finish secondary school education nine years later, and only some of them continue to graduate from high school. Dropouts and failures are partially attributed to the antiquated baccalaureate examination system. In 1970 and 1971 only 500 students graduated from high school in the whole country (200 in liberal arts and 300 in science). Since the total number of primary school students in Mali in 1960 was about 60,000 (Table III.2-2), approximately 5 percent of the total entering class in 1960 (roughly 10,000) has graduated from high school in 1971.

In vocational education, overall enrollments show a general drop in many centers. For example, at the Centre de Formation Professionelle at Bamako the total enrollment has dropped by about 16 percent and the total number of graduates by about 47 percent between 1967 and 1971

(see Table III.2-3). In 1970-1971, the Centre had a teaching staff of 70 full time teachers of whom 35 were foreigners.

This brief review of the education sector strongly suggests the need for substantial investments in education to (1) improve the internal efficiencies of the existing institutions, (2) to increase access to education of larger numbers of youth especially from the rural areas, (3) to enhance the capability of the secondary school system to produce the skilled manpower needed for development and to prepare larger numbers of students for higher education, and (4) to train larger numbers of general and vocational teachers both for the formal school system and for the many non-formal programs of vocational training now being mounted in the urban and rural areas in the Sahel countries.

The question of whether the Sahel countries should place greater investments and emphasis in the formal system which presently serves only 15 percent of the school-age population, or if non-formal educational programs in the urban and rural sectors should receive proportionately greater investment and attention cannot be answered unequivocally. A "mix" of both the approaches would be needed, but in the short run non-formal education programs closely related to major development projects in agriculture, transportation, and water resources are likely to provide the needed jobs for the rural population, as well as educational opportunities for adults and youth. For a more complete discussion of the issues in non-formal education, the conditions for success of non-formal education programs, the needed interrelationship between formal and non-formal education and the important question of leadership, see New Paths to Learning for Rural Children and Youth (Coombs et al. 1973). Case studies of non-formal programs conducted by ICED (International Council of Educational Development) point out the immense problems of coordination resulting from the multiplicity of non-formal out-of-school programs and the question of the realistic educational options provided

TABLE III.2-3

Enrollment at the Centre de Formation Professionelle

	Industrial	Commercial	Total
	1966-1967		
Enrollment	341	104	445
Graduates	132	24	156
	1970-1971		
Enrollment	245	129	374
Graduates	65	17	82

by these programs in very poor countries. Upper Volta's rural education system is an example of a good effort to provide a workable alternative to formal education. Even for non-formal educational programs, the questions of finding the large numbers of teachers and leaders for effective operation and the follow-up of the children until they find suitable jobs in the rural setting have yet to be answered in a satisfactory manner.

Several development agencies have been promoting programs of vocational and technical education in support of development programs in agriculture or mining (both through programs of a non-formal nature and through the formal educational system). For example, recent IDA loans have been made to Mali for "Operation Arachide" and to Mauritania for skilled worker training and to Koranic schools (interest free, 50 years with 10 years of grace, only a service charge of 3/4 of one percent to cover IDA's administrative costs). Such projects, as important as they are, will put additional pressure on the slender educational budgets of these countries and will increase the demand for local institutional and supervisory personnel. Proliferation of non-formal programs, when there is an inadequacy of teachers and supervisory personnel, is a real danger. One method of rapidly increasing the supply of such personnel would be to use programs of training already established in several west African countries (engineering technician programs in Nigeria, e.g. Kano Polytechnic and others in Nigeria and Ghana). Language would be a problem, as it would also be in other countries of Europe or the United States, except perhaps France. But the costs of such training are likely to be lower and the programs themselves more relevant to the needs of the Sahel countries. Development of local institutions with the help of expatriate teachers, concurrently with training outside the region especially within coastal west African countries, of technical teachers

and supervisors would be necessary for the next ten to fifteen years. Arguing for such investments in Mauritania the IDA states:

> Mauritania is predominently desert with less than a third of the land usable for livestock and only a narrow belt in the south adapted to agriculture. About 70 percent of the population of 1.2 million is nomadic and pastoral. The development of a modern sector, based mainly on the exploitation of iron ore deposits began in 1960 and for the next 8 years the economy grew at a rate of about 10 percent annually. However, very little of the benefits have reached the rural sector. By 1965 growth had slowed down to about 3-4 percent as mining companies reached their capacity and unprecedented droughts reduced the cattle herd by 40 percent and agricultural production by 60 percent.
>
> While development of the modern sector through further investments in iron ore, manufacturing industries and the transportation network must continue, the main emphasis will have to be on the development of agriculture, mainly through irrigation, of livestock and fisheries. Skilled workers at a level are needed both in the modern and rural sectors. This will require a major reorientation of the formal school system in which only 15 percent of the school age population is now enrolled and the provision of expanded training facilities.

3. INSTITUTIONS DEVOTED TO SCIENTIFIC AND TECHNICAL TRAINING AND RESEARCH

3.1 Review of Present Institutions

To the major professional training institutions must be added the small number of research stations in agriculture and animal husbandry and programs to combat the endemic diseases of the region.

A country-by-country canvass followed by detailed study of selected institutions and their requirements in equipment and manpower would be needed to assess their capacity and effectiveness in meeting their objectives. Until recently there were no serious inventories of institutions in science and technology in the region. As recently as January, 1974 UNESCO published two documents which describe surveys conducted by that organization with a view to determining national priorities in regard to scientific research and training. These are:

(1) Results of a UNESCO/UNACAST survey of institutional needs of African countries in the field of science and technology (UNESCO 1974a), and

(2) "Science and Technology in African Development," UNESCO Conference of Ministers of African Members of States Responsible for the Application of Science and Technology to Development (UNESCO 1974b).

Another UNESCO document (1970), "Survey on the Scientific and Technical Potential of the Countries of Africa" gives a preliminary inventory of African institutions and research workers in the principal scientific and technical disciplines. Many of these institutions are largely dependent on the previous colonial relationships with institutions in France for scientific manpower and other resources. Major technical institutions are shown in Table III.3-1.

It is clear from Table III.3-1 that there is a concentration of research and training institutions in Dakar. Furthermore, former branches

TABLE III.3-1

Major Technical Institutions of the Sahel-Sudan Region

CHAD	
Agronomy (General) and Hydrology	Direction des eaux et forets
Pedology	ORSTOM
Entomology, Ecology	IRCT
Crop Production and Protection	ORSTOM
Animal Health, Immunology	IEMVT
Animal biology	IEZVAC
Geophysics	Station allemande de Bardai
Geology	Direction des mines et de la geologie
MAURITANIA	
Hydrology	Service du genie rural
Crop Production and Agronomy	IRAT
Climatology	Bureau hydrogeologique
Cartography	Direction des mines et de la geologie
SENEGAL	
Agronomy (General)	ORSTOM
Construction Energy	Laboratoire du batiment et des travaux publics
Crop Production and Protection	ORSTOM
Soil Sciences	IRHO
Statistics	Faculte de Sciences, Universite de Dakar
Meteorology, Climatology	Institut de physique meteorologique
Civil Engineering	Laboratoire batiment et des traveaux publics

TABLE III.3-1 (continued)

SENEGAL (continued)	
Ecology	ORSTOM
Physiopathology	CNRA, ORSTOM
Public Health	Universite de Dakar, Institut Pasteur de Dakar
Animal Health	IEMVT
Geography and Cartography	Bureau de recherches geologiques et minieres
Computer Science	Universite de Dakar
Nutrition	IRHO and OCCGE
UPPER VOLTA	
Pedology, Agronomy, Agricultural Engineering, Horticulture, Plant Production and Protection	IRAT
Hydrology	ORSTOM
Public Health Epidemiology	OCCGE
Soil Sciences	IRHO

CNRA:	Centre national de recherches agronomiques de Bambey
IEMVT:	Institut d'elevage et de medecine veterinaire des pays tropicaux
IEZVAC:	Institut d'enseignement zootechnique et veterinaire d'afrique centrale
IRAT:	Institut de recherches agronomiques tropicales et des cultures vivrieres
IRCT:	Institut de recherches du coton et des textiles exotiques
IRHO:	Institut de recherches pour les huiles et oleagineux
OCCGE:	Organisme de coordination et de cooperation pour la lutte contre les grandes endemies
ORSTOM:	Office de la recherche scientifique et technique outre-mer

of French institutions in Senegal and other countries are devoted to a set of common research programs in agronomy, veterinary medicine, and health. Measures of the human and material resources available to these institutions and judgments about the quality of contributions made by these institutions to regional development are difficult to obtain.

3.2 Development of the Institutional System

The scientific and technological institutional system of a nation can be pictured to include four types of institutions or programs:

(1) institutions that generate knowledge (universities, research institutes or programs);

(2) policy-oriented institutions or agencies which concern themselves with issues of choice of technology, science policies, and resource allocation;

(3) application-oriented institutions, agencies and programs; and

(4) institutions or programs that explore, facilitate, and support linkages with national, regional, and international agencies and programs.

Increasing the autonomy and effectiveness of these institutions to enable them to undertake serious analyses of national problems and to fashion solutions within resources available to them, emerges as an important objective in the area of science and technology to be pursued by national governments and international agencies. As stated earlier, the drought has focused world attention on the countries of the Sahel which until recently was bypassed by developmentalists in favor of other regions whose problems look less intractable and whose manpower and physical endowments were more substantial than those of the Sahel. While relief operations are a necessary response to the immediate plight of the countries, it is our theses that the strengthening of indigenous

institutions is the sina qua non for progress of the region and this objective is best pursued from a long-range perspective.

3.2.1 Generation of knowledge about the Sahel-Sudan region: Planning for a long-range development program implies a basic understanding of the physical and climatological aspects of the region and especially a much better understanding of the history and culture of the peoples of the Sahel. Among the arid regions of the world, the Sahel is one of the least understood. Knowledge about the region, especially in the U.S., is still very meager and statements regarding problems and potentials of the region are often based on incomplete knowledge of the region or generalizations from experience in other arid regions. Even a modest list of projects of a scientific character would include the following:

(1) Systematic monitoring of the climatological changes in the Sahel and in west Africa; measurement of rainfall and evaporation rates;

(2) Population studies of animals and plant species in the region, (some experts have noted that the replacement of wild animal populations by domestic animals is one cause of desertification); relations between degradation of grazing lands and reduction of wild life (a source of pretein for the population);

(3) Studies of the chemistry of Sahelian soils leading to determination of areas and rates of erosion including preparation of soil maps, studies of salinity of soils, fertilizer responses, rates of decrease of soil fertility and bonding property and their relation to agricultural practices;

(4) Location, size, and changes in underground water reservoirs;

(5) Locust ecology; insect pests and their effect on vegetative barriers designed to prevent desert encroachment;

(6) Geological and mineral surveys; geothermal resources (in Mali and Chad); geographical and resource maps of the region;

(7) Demographic surveys, human settlement patterns, migration patterns of nomadic groups (people and animals); rural to urban migration studies, out-migration from the region;

(8) Anthropological and sociological studies of the different ethnic groups in the Sahel; structure of the family, social class, tribes, and patterns of political socialization; impacts of development programs;

(9) Nutrition surveys; adaptation of dietary patterns to nomadic life;

(10) Epidimeological studies of river blindness and other common diseases of the region;

(11) A more systematic study of education including enrollment, retention, institutional capacity and utilization, and costs at the elementary, secondary, and higher educational levels; estimates of skilled manpower, as well as an inventory of non-formal education programs, their objectives, location, source of funding, and implementation must also be provided.

Alternative institutional development patterns for generating more dependable basic information on the Sahel are listed below. Additional studies supported by visits to existing institutions in the region would be needed to detail manpower, physical facilities, and financial support needed for a specific program of institutional development in a given sector. However, an essential principle which we would recommend is that for sound long-range institutional development in the region, and because of the severe financial constraints under which any development plan in this region is likely to operate, every effort must be made to make use of the institutions in the west African region for development of the Sahel countries. Among alternatives for the development of scientific institutions in the Sahel the following appear to be feasible:

(1) Increased investment in the single leading university in the region (University of Dakar) to improve its facilities and indigenous staff,

and the establishment of new disciplines in science and engineering if necessary; use of the university as a resource base for training and research for all the Sahel-Sudan countries.

(2) Planning the development of one or two more national universities in countries where there are no universities at present or where isolated faculties tend to proliferate and waste limited resources.

(3) Establishment of a large externally funded scholarship program to prepare university staff, complemented by a program for the supply of qualified (language competence would be very important) expatriate professors preferably from the west African region to hold down teaching positions until those in training abroad return.

(4) Formation of a consortium of west African universities for the development of the Sahel; collaboration in research and training in a variety of disciplines; several university centers in Nigeria and Ghana are doing research on agriculture, nutrition, and water resources problems of particular relevance to the Sahel, but unfortunately strong linkages among institutions in these countries with corresponding ones in the Sahel do not now exist.

(5) Mission oriented single purpose research institutions in meterology or in endemic diseases of the region, or multi-purpose institutions to study a variety of ecological problems of the region have been suggested from time to time. In fact the former French-initiated institutions in each country listed earlier are now proceeding to consolidate their efforts, and this tendency must be encouraged so that the limited resources are concentrated on a few institutions. The temptation to start yet another international or regional center is often difficult to resist especially if external assistance appears likely. The more immediate and less wasteful effort would be to study the means by which existing institutions may be strengthened and reoriented to development objectives.

3.2.2 Policy making and its institutionalization: A simple tabulation of the process, purpose and criteria for science and technology policy would be as follows:

National Science and Technology Objectives (derived from national plans, party platforms and other sources)

Processes	Purpose	Criteria
Structure	Manpower	Support {Internal, External}
Design	Growth	Ideal feasible
Budgeting	Productivity {Capital, Manpower}	
Government	Minimize or avoid undesirable consequences of technology	
Actions-allocation of resources		
Private risk/costs		

In view of the human and material resource constraints of the Sahel-Sudan, it is clear that the governmental structures established for the formulation and implementation of technology policies should not be elaborate or expensive. Prior to the establishment of complicated forms of national councils of technology on the models of institutions in other LDC's, a basic need would seem to be the strengthening of the policy analysis and program implementation capacities of such government departments as public works, agriculture, education and health. A major program for the improvement of public administration in general deserves a high priority on the agenda of development programs of national governments and international agencies. Some of this training could be included in development projects financed by international banks in the sectors of education, agriculture, or transportation.

At the regional level, the strengthening of the capacity of organizations such as CILSS, the Senegal River and Lake Chad commissions in policy analysis including project evaluation would place them at some advantage in negotiations with external development agencies and investors and enable the countries to more successfully mobilize the local resources toward the attainment of specific development objectives.

3.2.3 Agencies for implementation of development programs: In the Sahel-Sudan region as elsewhere the two major users of technology are the government and the private industries. There is a virtual absence in the Sahel countries of institutions such as the industrial research, training and extension institutes found in many other LDC's. These institutions act to link their technology development and adaptation activities with industries. Because of the rudimentary nature of the technology now in use in the Sahel countries, the nature of institutions needed for technological development in the Sahel would be clearly different from those needed in the neighboring, more advanced countries of Nigeria or Ghana. The emphasis at this stage will need to be placed more on extension rather than sophisticated (and expensive) research and development activities in industrial technology.

With the industrial sector dominated by foreign capital and managers, the development of local commercial and development banks has been slow. Here is an opportunity to experiment with new approaches to provide technical assistance and small loans for capital and operating expenses to small local entrepreneurs such as shopkeepers, artisans, clothing and food processors, bus and truck companies and others who usually operate outside traditional banking mechanisms. Unfortunately, much more needs to be known about the structure of this level of economic activity, the characteristics of the entrepreneurs of the region and the sources of local capital. The "retailing" of whatever capital becomes available from external sources (U.N., bilateral programs, IBRD, A.I.D. grants and loans)

through national and local banking institutions to reach the small entrepreneur may necessitate the creation of entirely new institutions. For example, what national policies, agencies and mechanizations would be needed for a controlled redevelopment of the stocks of cattle decimated by the drought?

Research on technology policies within each of the Sahel countries and policies that should guide technological development through multinational alliances would include consideration of the following:

(1) the resources, such as technology-oriented manpower and the specific kinds of technological knowledge which are inputs to the processes of technological development;

(2) the overall process of industrialization and diffusion of technology in industry and the public sector; and

(3) the amelioration of the adverse consequences of technological change and the internalization of these consequences within the firm or the major development projects undertaken.

Governments, regional economic and political alliances and international agencies influence these through a variety of mechanisms. Studies are needed on the effectiveness of the incentives and disincentives now used and of alternative policies and mechanisms needed to spur economic development of the region. Among them are those that:

(1) work through market forces (government or international agency produrement practices, tariff and import quota policies, tax incentives, local or state buying consortia);

(2) encourage market invasion by new and old firms (providing venture capital, counseling and legal services, support for research and development activities, government procurement practices, direct development contracts);

(3) structuring the industrial sector (through government chartered or owned firms, granting monopolies or through international consortia);

(4) reducing the cost to firms for undertaking development activities under the unfavorable climatic, and market conditions of the Sahel, (low-cost interest-free loans, loan guarantees, direct subsidies, tax deductions, investment tax credits, loans or grants for regional development);

(5) reducing the probability of technical or commercial failure (cost-plus contracts, export incentives and subsidies, technical assistance);

(6) increasing rewards to firms for successful involvement in the development of industries in the region (favorable tax treatment, exclusive licenses, tax loss carry-forward provisions).

3.2.4 Linkages of Sahel institutions among themselves and with those outside the region: Drawn together by common economic and social problems and recently by the tragedy of the drought, the Sahel countries are already participating in a variety of regional arrangement for development. It is not the paucity of institutions or associations but their number and variety that are impressive here. The study of the effectiveness of these organizations to link development activities in the region and with sources of information, advice, technical assistance, and financing is a task larger that can be attempted here.

The point has been repeatedly made that the economic and technological future of the land-locked countries of the Sahel-Sudan region is inextricably ties up with those of the west African coastal countries. The concept of a "common market" as the ultimate goal and one which would include the countries of the Sahel-Sudan and the west African countries would imply the development of strong linkages among institutions involved in development at almost every level of policy making and implementation in education and research, integrated agricultural and livestock development, in high level and skilled manpower development, and in transportation and infrastructure development. To the sovereign

states of the Sahel-Sudan region and to the external aid and development agencies alike, the allocation of resources between the competing demands of national development and their coordination with regional development objectives (and with the variety of institutions for regional collaboration) will pose several dilemmas. The rapidly dwindling amount of concessional aid available and the competition for these funds among the twenty-five or so of the least developed countries of the world makes the allocation of the scarce resources even more difficult. From a long-range standpoint, development experience elsewhere has shown that the development of the human resources and, through them, the strengthening of local policy making and implementation infrastructure of the region assumes high priority. The external development agencies are most likely to find this an attractive, easily scheduled, and low cost way of assisting the region over the long run, unless the discovery of hitherto unknown resources within the region improves its geo-political and economic importance beyond the present bleak prognosis of the region's viability.

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APPENDIX 1

Economic Planning in Arid Zones

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William W. Seifert

1. INTRODUCTION

One of the characteristics of arid zones is the highly variable climatic regime to which they are subjected. Under these conditions spatial and temporal weather variability is so pronounced that it makes little sense to use "average" conditions for economic planning. The purpose of this paper is to demonstrate that use of average conditions leads to generally misleading conclusions and to illustrate a method of analysis which may be associated with various econometric models to introduce into them some of the impacts of weather variability.

The Sahel-Sudan region of west Africa (Chad, Mali, Mauritania, Niger, Senegal, and Upper Volta), which is a typical arid zone, has an economy largely based on agriculture production. Therefore, the impact of climatic variability would be expected to be pronounced.

We made use of a macro-economic model, formulated initially by Chenery and Strout (1966), and later adapted to the Sahel-Sudan region as described in the macro-economic analysis volume of this report series (Annex 1) to illustrate the weather-economic interactions. This study reviews briefly the Chenery-Strout model, then discusses the additional assumptions which were made, and finally presents the results of a Monte Carlo simulation which takes into account the variability of rainfall.

2. THE CHENERY-STROUT MODEL

This model uses the following relations:

$$V_t = V_{t-1} + \frac{I_{t-1}}{K} \qquad (1)$$

$$S_t = S_{t-1} + \alpha (V_t - V_{t-1}) \qquad (2)$$

$$I_t \leq (1 + \beta)\, I_{t-1} \qquad (3)$$

$$V_t \leq (1 + \bar{r})\, V_{t-1} \qquad (4)$$

$$M_t = M_{t-1} + \mu\, (V_t - V_{t-1}) \qquad (5)$$

$$E_t = E_{t-1}\, (1 + \varepsilon) \qquad (6)$$

$$V_t = S_t + C_t \qquad (7)$$

$$F_t = \max\, \{I_t - S_t\, ,\ M_t - E_t\} \qquad (8)$$

The indices t-1 and t denote the time periods; in this case yearly increments were considered. Relation (1) implies that gross national product V has a yearly increase equal to the last annual investment I_{t-1} divided by the prevailing capital/output ratio K.

Relation (2) assumes that the gross domestic savings S increase by an amount proportional to the annual increase of GNP. The constant of proportionality α is called the marginal savings rate.

Relation (3) represents a constraint on the annual rate of growth of gross investments I. This rate of growth cannot exceed β which is an aggregated variable representing the absorptive capacity of the economic system.

Relation (4) is a constraint on the annual rate of growth of GNP which may not exceed the target rate $\bar{r}$.

Relation (5) describes the growth of imports M which are assumed

to increase proportionally to the GNP. The constant of proportionality, or marginal import rate is denoted by μ .

Relation (6) describes the rate of growth of exports E which are assumed to grow at an annual rate ε .

Relation (7) simply states that the gross national product V is the sum of consumption C and gross domestic savings S.

And finally, in relation (8), F is the required amount of foreign assistance; it is represented by the maximum of the two possible gaps: investments minus savings, or imports minus exports. During the early stages of development, the savings gap tends to be the most severe constraint, while the balance of trade gap tends to be representative of more developed countries.

Our purpose here is not to discuss this model since it is used primarily for illustrative purposes. Therefore we will only present the input data chosen for the basic case, which is a macro-economic projection for Senegal for the period 1975 to 1995 (Annex 1 of M.I.T. report series).

The target rate of growth of GNP, $\bar{r}$, is chosen as 5 percent, and the marginal import rate is 0.25. Moreover, it is assumed that the capital/output ratio K is equal to 6 during the first five years, decreases to 5 during the following five years, and further decreases to 4 for the remainder of the twenty-year period. The marginal savings rate α increases progressively from an initial 0.12 to 0.15, 0.20 and 0.25 at five-year intervals. ~~The absorptive~~ capacity, factor β increases progressively from an initial 0.12 to 0.15, 0.20 and 0.25 at five-year intervals. The absorptive capacity, factor β increases from 0.10 during the initial five years to 0.12 for the following fifteen years. Finally, the rate of growth of exports ε increases from 0.045 during the first decade to 0.06 during the second decade. The initial values of the other economic variables, along with the results of this base run, are

presented in Table 1.

These results show that a GNP of 525 billion FCFA is achieved in 1995, (starting at an initial 208 billion FCFA), while the cumulative (non-discounted) amount of foreign assistance is 458 billion FCFA ($U.S. 1.8 billion). On a per capita basis this is equivalent to $198 in 1975 and $321 in 1995, i.e., an annual growth of 2.44 percent for the per capita GNP. The population is taken to grow at an annual rate of 2.25 percent from 4.2 million in 1975 to 6.55 million in 1995.

3. THE MODIFIED MODEL

Some assumptions relating to rainfall and economic factors were made. These assumptions modify the Chenery-Strout model to account for weather variability.

3.1 Capital/Output Ratio: In the Sahel-Sudan region an average of 60 percent of the GNP is derived from agriculture. Since this production depends to some extent on rainfall, the GNP will fluctuate as a function of rainfall, everything else being equal.

Data analyzed by Verhaeghe (1974), demonstrate that statistical correlations between yield and rainfall may be established for various crops in the Sahel-Sudan. For instance, a one-millimeter decrease in precipitation produces a one-kilogram/hectare decrease of millet productivity, a half-kilogram/hectare decrease of sorghum productivity, and no change of groundnut productivity. Of course, actual relations are more complex; for example, although groundnut productivity seems to be insensitive to changes in total rainfall, this assumption would certainly not hold for large changes of total precipitation values. It is obvious that no groundnuts will grow for the extreme case of zero precipitation. However, actual relations may be obtained given sufficient data.

TABLE 1

Base Run (5 percent)

	V	I	S	I - S	M	E	M - E	F	ΣF	ΔV/V	ΔI/I
	GNP	INVESTMENT	SAVINGS		IMPORTS	EXPORTS		FOREIGN AID	CUMULATIVE	ANNUAL RATES OF GROWTH	
1975	208.00	42.00	24.10		59.90	48.80		17.90	17.90		
1976	215.00	46.20	24.94	21.26	61.65	51.00	10.65	21.26	39.16	0.0336	0.1000
1977	222.70	50.82	25.86	24.96	63.57	53.29	10.28	24.96	64.12	0.0358	0.1000
1978	231.16	55.61	26.88	28.73	65.69	55.69	10.00	28.73	92.85	0.380	0.0942
1979	240.43	61.05	27.99	33.06	68.01	58.19	9.81	33.06	125.90	0.401	0.0979
1980	252.45	63.14	30.77	32.37	71.01	60.81	10.20	32.37	158.28	0.0500	0.0342
1981	265.07	66.29	32.66	33.63	74.17	63.55	10.62	33.63	191.90	0.0500	0.0499
1982	278.33	69.57	34.65	34.92	77.48	66.41	11.07	34.92	226.83	0.0500	0.0496
1983	292.24	73.08	36.73	36.35	80.96	69.40	11.56	36.35	263.18	0.0500	0.0504
1984	306.85	76.69	38.93	37.77	84.61	72.52	12.09	37.77	300.94	0.0500	0.0494
1985	322.19	80.54	41.23	39.31	88.45	75.78	12.66	39.31	340.25	0.0500	0.0501
1986	338.30	67.65	50.16	17.49	92.47	80.33	12.14	17.49	357.75	0.0500	-0.1600
1987	355.21	71.04	53.54	17.50	96.70	85.15	11.55	17.50	375.25	0.0500	0.0501
1988	372.97	74.60	57.09	17.50	101.14	90.26	10.88	17.50	392.75	0.0500	0.0500
1989	391.61	78.36	60.82	17.54	105.80	95.67	10.13	17.54	410.29	0.0500	0.0504
1990	411.19	82.19	64.75	17.44	110.70	101.41	9.28	17.44	427.73	0.0500	0.0489
1991	431.74	86.34	80.04	6.31	115.83	107.50	8.33	8.33	436.07	0.0500	0.0506
1992	453.32	90.68	85.42	5.26	121.23	113.95	7.28	7.28	443.35	0.0500	0.0503
1993	475.99	95.18	91.10	4.08	126.90	120.79	6.11	6.11	449.46	0.0500	0.0496
1994	499.78	99.95	97.05	2.90	132.85	128.03	4.81	4.81	454.27	0.0500	0.0500
1995	524.77	104.91	103.30	1.61	139.72	135.72	3.38	3.38	457.64	0.0500	0.0497

From the agriculture section of the M.I.T. report series (Volume 2), we find that millet and sorghum constitute 60 and 15 percent respectively by weight of total agricultural production in the Sahel-Sudan region. If we neglect animal production and use a weighted relation, we find that a one-millimeter change of rainfall produces an average 0.16-kilogram/hectare change in agricultural productivity. Assuming an average productivity of 500-kilogram/hectare and an average rainfall of 600 millimeters, one derives that a one-percent change in rainfall produces one-fifth of a percent change in agricultural production. Since we assume that 40 percent of the economy is not sensitive to rainfall variability, then a one-percent change in rainfall produces one-eighth of a percent change in GNP, everything else being equal.

This result is included in relation (1) by making the capital/output ratio K a function of rainfall. A one-percent decrease in precipitation increases all the capital output ratios by one-eighth of a percent.

3.2 Marginal Savings Rates: Marginal savings rates α are assumed, arbitrarily, to change as a function of the rate of change of GNP. When GNP increases at an annual rate r, the marginal savings rate is increased by a factor of $2r$ over its base value. For instance, if the average savings rate is 0.12 (for zero growth), a 5 percent GNP growth will be reflected in a modified value of α which becomes 0.132; while if GNP drops by 5 percent, the savings rate becomes 0.108.

3.3 Absorptive Capacity Factor β : It is assumed that a drought will divert some of the institutional capacity of the region, therefore decreasing the upper limits on investments, while bumper crops may act to raise these limits. It is further assumed that limits on investments are functions, not only of conditions during the present year,

but of conditions during the past three years. This memory characteristic is included by modifying relation (3):

$$I_t \leq (1 + 2\beta) \frac{(I_{t-1} + I_{t-2} + I_{t-3})}{3} \qquad (9)$$

Moreover, the basic β is modified by a weighted factor of the current year's precipitation (weight = 2/3) and previous year's precipitation (weight = 1/3). For example, if the current precipitation is 10 percent below average, and the previous precipitation is 10 percent above average, then β is multiplied by the factor:

$$\{ \quad 1 + \frac{1}{4} \left[\frac{2}{3} \times \left(\frac{-10}{100}\right) + \frac{1}{3} \left(\frac{10}{100}\right) \right] \quad \} \quad = \quad 0.99.$$

3.4 Marginal Import Rate μ : The import rate is also a function of agricultural production. Since food represents an average of 20 percent of the value of imports at present, import requirements may be estimated to increase by 0.025 percent for every percentage point decrease of precipitation.

3.5 Rates of Growth of Exports: A decrease of agricultural production would affect exports. We assumed that the rate of growth of exports ε increases (or decreases) by half the percentage of variation of rainfall from its average.

3.6 Rainfall Variability: Yearly precipitation was assumed to have a Gaussian distribution. Although the coefficient of variation of rainfall over the Sahel-Sudan region was estimated at 0.25, the illustrative runs used 0.10 as a coefficient of variation as representing a conservative figure. Moreover, no year-to-year correlations were included in the present set of assumptions. Future refinements could account for more accurate representations of rainfall variability such as the mixed incomplete gamma distribution suggested by McQuigg (1974).

4. RESULTS

The principal numerical results are summarized in Table 2. These analyses are compared: a 5 percent base run, a 4.1 percent base run, and a simulation which includes weather variability. In all of these cases, the program as described in section 2 includes a constraint on the maximum annual rate of growth of the GNP. However, other constraints could have been included. For instance a constraint on the maximum annual value of foreign assistance, or a constraint on the minimum rate of growth for consumption might be more realistic. Different sets of constraints would produce different results. However, the cases which were run, provide most of the needed insight concerning the impact of rainfall variability on macro-economic projections.

The GNP projections for 1995 produced by the simulation runs range between $1,580 million and $1,960 million. The average projection is $1,870 million. This value represents an average rate of growth of the GNP of 4.1 percent. Therefore, the target annual rate of growth of 5 percent was reduced to an effective rate of growth of 4.1 percent when climatic variabilities were accounted for. In this case a 10 percent coefficient of variation for rainfall produced almost 20 percent drop in the average rate of growth of the GNP. Figure 1 shows typical simulation projections of the GNP and compares them to the two base runs which do not account for climatic variations. The histogram of Figure 1 indicates a skewed distribution for the projected GNP values, with a maximum variation of projected GNP values of $\pm$ 10 percent around the mid-range value.

Required foreign assistance over the 1975-1995 period averaged $1.35 billion (FCFA 335 billion) for the simulation runs. This represents a drop of 25 percent from the $1.8 billion projected by the 5 percent base run. However, this estimate of the foreign assistance is

TABLE 2

Summary Results

	1975	1995	Annual Rate of Growth (percent)
Population	4.2M	6.55M	2.25
GNP			
Base Run (5 percent)	$832M	$2,100M	4.74
Base Run (4.1 percent)	$832M	$1,836M	4.04
Average Simulation	$832M	$1,872M	4.14
Minimum Simulation	$832M	$1,580M	3.26
Maximum Simulation	$832M	$1,960M	4.38
GNP/Capita			
Base Run (5 percent)	$198	$132	2.44
Base Run (4.1 percent)	$198	$280	1.75
Average Simulation	$198	$286	1.86
Minimum Simulation	$198	$241	0.99
Maximum Simulation	$198	$299	2.08
Cumulative Foreign Assistance			
Base Run (5 percent)		$1,800M	
Base Run (4.1 percent)		$ 660M	
Average Simulation		$1,350M	
Minimum Simulation		$ 440M	
Maximum Simulation		$2,320M	

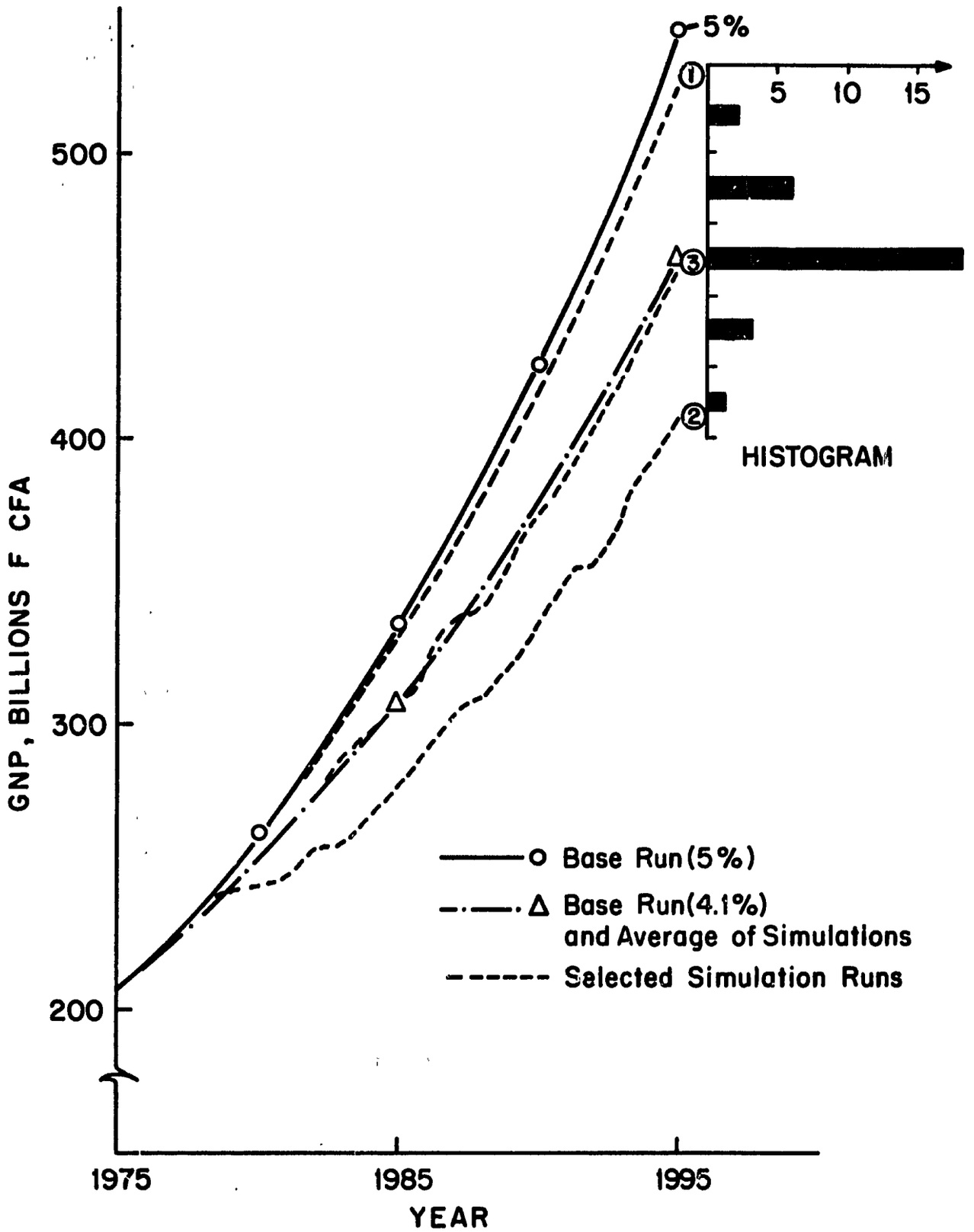

FIGURE 1 Projected GNP (Senegal)

double that obtained from the 4.1 percent base run which produces the same rate of growth of the GNP under constant climatic conditions. Figure 2, which compares the projected cumulative requirements for foreign aid, shows that climatic variations increase the need for foreign aid and produce wide variations in the projected needs for foreign aid. The histogram on Figure 2 shows a possible bimodal distribution; it also shows that the 10 percent coefficient of variation of rainfall produced a maximum variation of over 50 percent in the projected foreign aid requirements around their mid-range value. This variability of foreign assistance is illustrated by the selected simulation runs. For example, the curve labeled 3 in Figure 1 produces nearly the same GNP in 1995 as the non-stochastic 4.1 percent base run, i.e. 460 billions FCFA. However, as shown in Figure 2 the impact of what amounted to be a favorable climate reduced the needed foreign assistance from 165 billions FCFA (non-stochastic 4.1-percent base run) to 115 billions FCFA. On the other hand, the curves labeled 2 which result in the low GNP value of 405 billion FCFA, required a foreign assistance of as much as 205 billion FCFA.

Thus, we may conclude that when 10 percent rainfall variability was accounted for, the GNP projected over a twenty-year period was lowered, on the average, by a little over 10 percent. The projected distribution of GNP values is skewed with maximum variations of ± 10 percent around the mid-range value. The expected foreign aid requirements to produce a given rate of growth of the GNP, doubled when the climatic variation was included. Moreover, foreign assistance requirements were highly variable as functions of rainfall variations. The maximum variation of the cumulative foreign assistance requirements over the twenty-year period was ± 50 percent around the mid-range. If

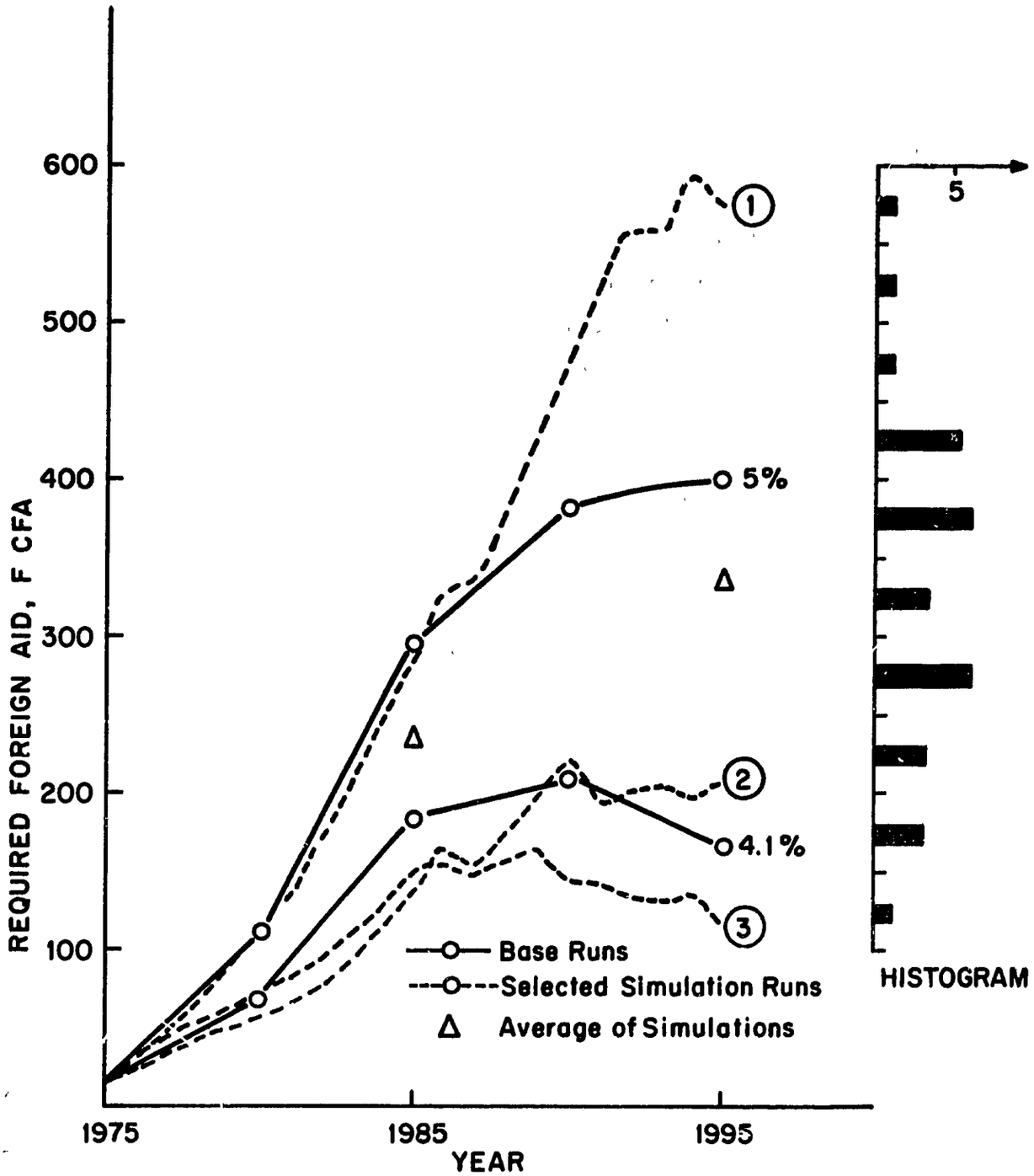

FIGURE 2 Projected Cumulative Requirements for Foreign Aid (Senegal)

the principal constraint had been the annual amount of foreign assistance the variability of the projected GNP would have been very large.

Therefore, if economic projections have to be made using average rainfall conditions, they should be scaled down to values less than those obtained using the average rainfall condition. The scaling factor should be somewhat smaller than "one minus the rainfall coefficient of variation." Moreover, it should be realized that calculated values for foreign assistance are greatly underestimated and that foreign assistance should be highly flexible to adapt itself to weather variability.

This method of analysis was proposed only for illustrative purposes. In order to use it in practice, most of the assumed relations should be reevaluated.

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APPENDIX 2

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