PN-AAU-020
42625

The University of Michigan
Gambia River Basin Studies

Water Resource Management and Gambia River Basin Development

Prepared for
U.S. Agency for International Development (USAID)
and Gambia River Basin Development Organisation (OMVG)
Contract No. 685-0012-C-00-2158-00

September 1985

DEDICATION

This volume is dedicated to the late Karl F. Lagler, field director of the Gambia River Basin Studies, who died suddenly in Ann Arbor on August 25, 1985. From January 1983 to December 1984 Dr. Lagler presided over field research operations from headquarters in Banjul. Drawing on his years of experience and prior work in the Mekong River Basin, he urged on his colleagues the concept of a fully integrated approach to the development of the Gambia River Basin. This synthesis report reflects his vision. Significant portions of it are the result of his contributions.

PREFACE AND ACKNOWLEDGEMENTS

This is the synthesis report of the University of Michigan Gambia River Basin Studies, which were conducted with the assistance of Harza Engineering Company of Chicago, Illinois, with funding by the United States Agency for International Development through its River Basin Development Office in Dakar, Senegal. This report is designed for decision makers and planners of the Member State governments -- The Gambia, Guinea, Guinea Bissau, and Senegal -- and of the Gambia River Basin Development Organisation (OMVG) to enable them to evaluate proposed investments in the construction of five dams and in irrigated agriculture.

This report synthesizes the results of four primary field studies, which are presented in the four companion reports:

- Aquatic Ecology and Gambia River Basin Development
- Terrestrial Ecology and Gambia River Basin Development
- Water-Associated Diseases and Gambia River Basin Development
- Rural Development in the Gambia River Basin

This report also draws upon the numerous GRBS Working Documents produced by the Gambia River Basin Studies (listed in Annex A). It furthermore presents original benefit/cost and other analyses required for the synthesis.

We are indebted to the leaders and senior investigators of the four field study teams. Valuable contributions to this report have been made by Russell Moll and John Dorr in the area of aquatic ecology; by Peter Ames, Dario Rodriquez, and Dean Treadwell in the area of terrestrial ecology; by Curt Schneider in the area of public health; and by William Derman, Frank Casey, Cynthia Moore, Christine Elias, Rolf Jensen, and Andrée Wynkoop in the area of rural development. The authors of the various working documents we draw upon also have provided valuable information, especially Lucie Colvin, Michael Jasinski, Henri Josserand and Marty Makinen.

The Gambia River Basin Studies were initiated by Kenneth Shapiro (and the late Karl Lagler), while John Sutter and Alfred Beeton played crucial roles early in the project. The field office in Banjul, The Gambia, provided valuable support under the direction of Dr. Lagler and the administration of Songthara Omkar. John Chitty served most capably as project coordinator for Harza Engineering. He also helped prepare the terrestrial ecology report.

Field activities and preparation of the reports required the professional assistance of the staff of the Center for Research on Economic Development at the University of Michigan. Sherry Cogswell provided the primary logistical support.

Carol Wilson was responsible for producing the reports, and their professional quality is due to her extraordinary efforts as well as the dedicated expertise of Patricia Humphrey and Rebecca Doyle, who were responsible for producing camera-ready copy. The artwork was prepared by Gretchen Jackson, Sandy Conrad, and Jane McCormick. All worked in the face of unreasonable deadlines.

Completion of the Gambia River Basin Studies ultimately depended on the guidance and support of USAID and OMVG staff in Dakar. Vito Stagliano of USAID was especially influential in the design of the five primary project reports. Lewis Lucke was immensely helpful as USAID project officer for our field studies and provided valuable assistance as we prepared our reports. David Hunsberger provided logistical assistance for the Banjul office and the field studies.

The studies benefitted from the cooperation and advice of OMVG staff as well. OMVG has become firmly established under the leadership of Mr. Malik John as the agency responsible for planning development of the Gambia River Basin. Throughout our stay in the field, Mr. Mamour Gaye, the technical director of OMVG, lent his support and his guidance. The technical staff of OMVG was important to our investigation, and the contributions of Andre DeGeorge, James Webb and Gordon Appleby were especially important. We are indebted to these as well as to numerous persons in the agencies of the Member State governments for their assistance in conducting our field studies and in providing information.

The final reports bear the imprint of our colleagues in the United States as well. A midterm project evaluation report helped us clarify our objectives as we prepared for the final field investigations and the initial drafts of these reports. This team consisted of James Osborn, the leader, Nicholas Sonntag, Janet Futhill, Dolores Koenig, and Glenn Anders. The commentaries of the panelists of the National Science Foundation review of the project at its conclusion, conducted by Irwin Pikus of the National Science Foundation, were extremely influential. The commentary of Thayer Scudder, the chair of the review panel, was especially useful as we revised the final draft of this synthesis report. We have incorporated his comments wherever it was possible to do so. The suggestions of other panel members, especially Charles Howe and Gilbert White, also considerably strengthened the report.

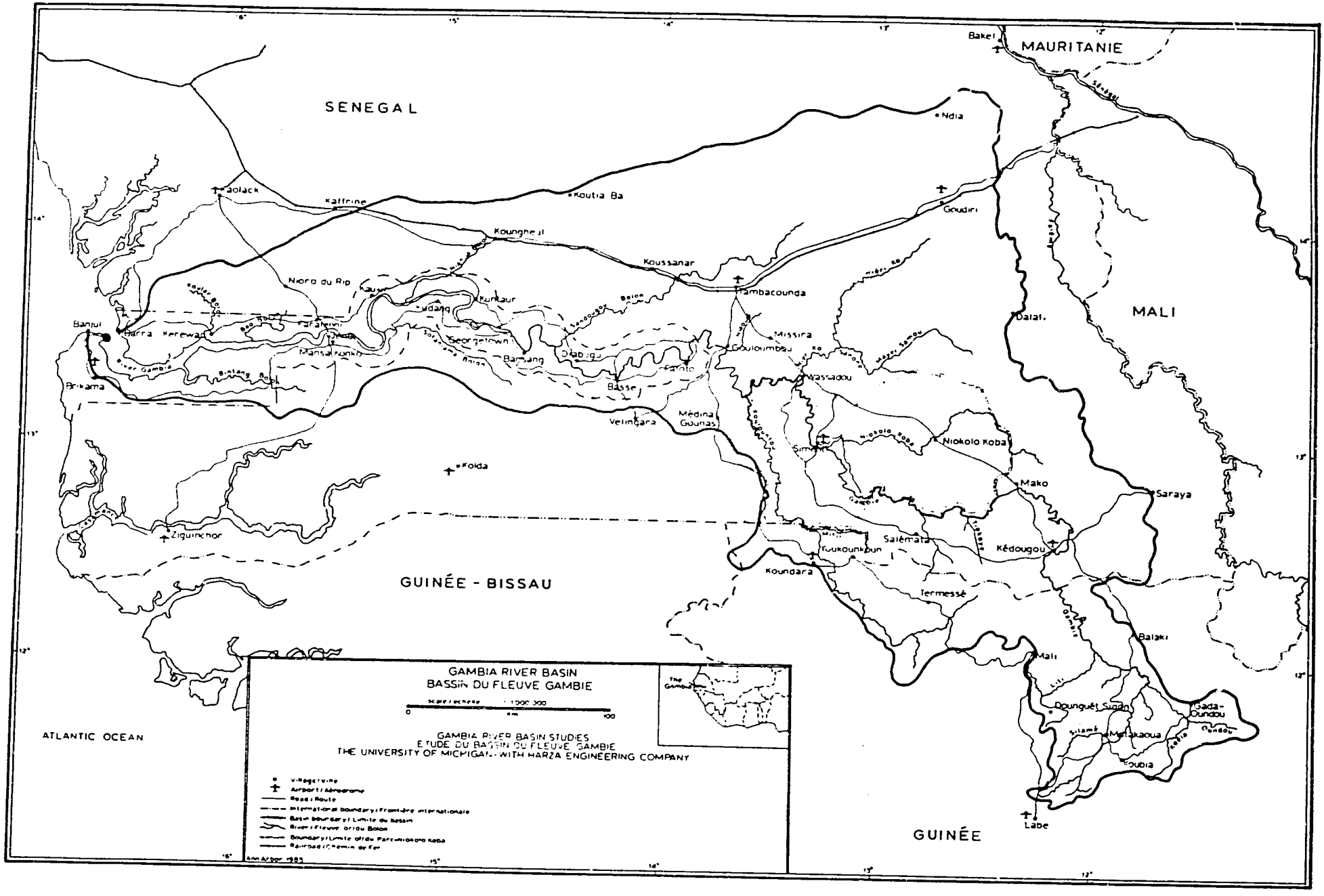
This synthesis report, furthermore, could not have been prepared without the contributions of colleagues whose assistance was solicited. Charles Steedman helped us in editing. James Fitch prepared some of the agricultural economic

analyses upon which the synthesis report depends. Sarah Lynch wrote two chapters of this report and should be considered a coauthor.

This synthesis report therefore represents the efforts of numerous persons whose contributions were essential to the successful completion of the Gambia River Basin Studies.

Ann Arbor, Michigan
September 1985

J.C. Mathes
Elon Gilbert


GAMBIA RIVER BASIN
BASSIN DU FLEUVE GAMBIE
GAMBIA RIVER BASIN STUDIES
ÉTUDE DU BASSIN DU FLEUVE GAMBIE
THE UNIVERSITY OF MICHIGAN - WITH HARZA ENGINEERING COMPANY
SENEGAL
MAURITANIE
MALI
GUINÉE - BISSAU
GUINÉE
ATLANTIC OCEAN
Bakel
Ndia
Kaolack
Kaffrine
Koutia Ba
Goudiri
Koungheul
Koussanar
Tambacounda
Nioro du Rip
Kuntaur
Banjul
Barra
Kerewan
Farafenni
Mansakonko
Georgetown
Bansang
Dabagou
Fatoto
Basse
Missira
Gouloumbou
Wassadou
Dalaf
Brikama
Velingara
Médina Gounass
Simenti
Niokolo Koba
Mako
Saraya
Kolda
Ziguinchor
Salémata
Kédougou
Kououkoun
Koundara
Termessé
Balaki
Mali
Dounguét Sigan
Gada-Oundou
Melakaoua
Foubia
Labe

EXECUTIVE SUMMARY

These Gambia River Basin Studies were undertaken to analyze the impacts of specific water resource development projects proposed for the watershed of the Gambia River Basin. The Member States -- The Gambia, Senegal, Guinea, and Guinea-Bissau -- have charged the Gambia River Basin Development Organisation (OMVG) with exploring the feasibility of the proposed development projects. To assist OMVG in this task, the United States Agency for International Development (USAID), through its River Basin Development Office (RBDO) in Dakar, Senegal, contracted with The University of Michigan with assistance from Harza Engineering Company of Chicago, Illinois, to conduct environmental, socioeconomic, and public health studies.

The Gambia River Basin Studies have produced five primary reports, numerous working documents, and a set of land-use maps for the basin. In addition to this report on Water Resource Management and Gambia River Basin Development, the primary reports are:

- Aquatic Ecology and Gambia River Basin Development
- Terrestrial Ecology and Gambia River Basin Development
- Water-Associated Diseases and Gambia River Basin Development
- Rural Development in the Gambia River Basin

The four subject-area reports are designed to be read separately by various users for different purposes. They are integrated in this synthesis volume, the fifth of the primary reports.

The reports have a range of uses from basic planning and decision making to field level implementation of resource management and impact mitigation measures in at least four broad areas:

- development policy and decision making
- development project planning
- river basin monitoring and institutional development
- implementation of and adjustment to impact mitigation measures

The five primary reports will help OMVG further to establish itself as an effective coordinating agency for development of the water resources in the basin.

These studies investigated the socioeconomic and environmental implications of plans for construction of five dams in the Gambia River System -- Balingho in The Gambia, Kekreti in Senegal, and Kouya, Kankakoure, and Kogou Foulbe in Guinea.

In addition, they investigated the implications of significant expansion of irrigated agriculture in the basin. Construction of the dams and expansion of irrigated agriculture represent a coordinated set of projects which will have impacts throughout the basin.

The overall objective of Gambia River Basin development is to better "the lives of the people in the basin," according to the OMVG Draft Indicative Plan. Specifically, this involves:

- achieving food self-sufficiency
- increasing per capita income
- promoting industrial development
- improving national balances of payments
- enhancing the quality of life
- preserving environmental quality

As these studies suggest, however, the specific projects we investigated may not contribute to reaching these objectives as much as was originally envisioned. Progress toward achieving food self-sufficiency and improving national balances of payments may come only at the expense of important aspects of the quality of life and the environment in the basin.

Perhaps the most important implication of these studies concerns the need for additional planning rather than for immediate decisions. The trade-offs among various development options should be analyzed in terms of the probabilities of certain impacts occurring. They should be evaluated in terms of the values and expectations of Member State planners and decision makers. As OMVG and the Member State governments realized from the outset, river basin development is exceedingly complex. Initial proposals and decisions, therefore, must inevitably be modified after they are studied in detail. Our studies have examined initial proposals and, as a consequence, suggest directions for further investigation by OMVG and Member State governments before irrevocable decisions are made.

Framework for Impact Analysis

Our primary approach has been to analyze the impacts of development projects throughout the basin rather than project by project. Our basic categories of impacts are those related to management actions in various environmental and socioeconomic systems. We summarize the significant impacts in terms of the basin as a whole, of a single project, or of a combination of projects. Given the initial

(Senegambian) mandate for our field studies and the lack of feasibility studies on the Guinean sites, of necessity we focus on the impacts of the Balingho Dam, Kekreti Dam, and irrigation agriculture projects more than of the Guinea dams.

The impacts of the proposed dams must be considered within the framework of the hydrologic implications of the basic operational policies of the proposed dams and reservoirs. The purpose of Balingho Dam is to prevent saltwater intrusion beyond Balingho. This is presumed to allow development of irrigated agriculture on land primarily upstream from Carrol's Wharf, river km 220, past which point the salt frontier has penetrated in recent drought years. Most of the irrigation water, however, will be released from Lake Kekreti, as only a maximum of 5,000 hectares (ha) of irrigation is considered possible with water from Lake Balingho.

Kekreti Dam will produce hydroelectric power and will provide water year-round for irrigation of up to 70,000 ha as well as maintain the water level in Lake Balingho. Recently, simulations have been conducted on the autonomous operation of Kekreti Dam for the additional purpose of controlling saltwater intrusion without a dam at Balingho. This essentially involves a trade-off between water use for irrigation and water release to control penetration of the salt frontier. Hydroelectric power generation would be relatively unaffected by the autonomous operation of Kekreti Dam if an optional third turbine were to be installed in the dam.

However, in accord with the base scenario proposed by OMVG, we assume the tandem operation of Balingho Dam and Kekreti Dam rather than the autonomous operation of Kekreti Dam. Thus, we assume that the salinity frontier will be held by Balingho Dam the year-round and that Lake Balingho will be formed as a freshwater lake behind the dam. We assume that Lake Kekreti will fill approximately to capacity each year and that up to 70,000 ha will be developed for irrigation over a 50-year period.

Planning for the dams in Guinea is in the prefeasibility stage; thus, their operational policies have not been formulated. Kouya Dam on the Gambia River is the largest structure proposed for the Gambia River Basin, and primarily will provide hydroelectric power. Kankakoure is a small dam on the Liti River that will generate hydroelectric power. Kogou Foulbe Dam on the Koulountou River will generate hydroelectric power and provide water for irrigation of 12,000 ha.

The impacts of basinwide development prominently include the irrigation agriculture projects that will become possible as a result of water resource

development. Currently, the 3,000 ha already developed seem the limit of what can be irrigated in the dry season because of the seasonal character of freshwater flow and of the penetration of the salt frontier upstream. For The Gambia and Senegal Oriental, feasibility studies of the development of irrigation agriculture between Balingho Dam and Kekreti Dam have progressed to the stage where soils have been classified so that the exact locations of areas with irrigation potential have been identified. Although feasibility studies for irrigation in Guinea have not yet been initiated, the areas for irrigation from Kogou Foulbe Dam and Kouya Dam have been identified.

Basinwide development plans assume that a total of 85,000 ha of land is suitable for irrigation: 53,500 ha in The Gambia, 16,500 ha in Senegal Oriental, and 15,000 ha in Guinea. A minimum of 30,000 ha in The Gambia are planned for development from 30 to 54 years after Kekreti Dam is built. Three alternative strategies for incorporating irrigation into existing farming systems are represented by the Bansang Nibras Pilot Project in The Gambia, the Jahaly Pacharr Project irrigation perimeter and improved swamp rice schemes in The Gambia, and the Périmètres Irrigués du Sénégal-Oriental project.

Impacts on the Environment and Current Land Use

The most widespread and significant impacts on the environment and current land use will be those associated with the construction of Balingho Dam and the formation of Lake Balingho. The Kekreti and Guinea projects will be less disruptive, although the project at Kekreti could jeopardize the integrity of Niokolo-Koba National Park unless management precautions are taken.

- Water surface area. The four dam projects will more than double the water surface area in the basin. Currently, water covers 1,060 km^2 of the basin. The five man-made lakes will have maximum surface areas of 1,200 km^2, almost all of which will be in addition to the current water surface area. At the end of the dry season, however, the man-made lake surface area may be less than 400 km^2 -- an annual variation of 800 km^2. This would create a "drawdown" area with considerable development potential, especially for agriculture.
- Vegetation cover. The existing land-use and vegetation cover in the basin will be minimally affected in quantitative terms by development projects. The

percentage of total land affected will be small. The qualitative impacts, however, will be significant.

- Balingho Dam. Balingho Dam will eliminate the tidal influence that now extends upstream as far as Gouloumbou and will intensify tidal amplitudes below the dam. The lack of tidal mixing eventually will cause tidal creeks and streams (bolons) to fill with sediment and become stagnant. All of the mangrove forest above the Balingho site, some 8,000 ha or 12 percent of the total mangrove forest in the basin, will be eliminated. The barrier will also all but eliminate the estuarine environment, as salinity will not decrease from the mouth of the Gambia River to the dam. In addition, it will block the flow of nutrients from upstream into the estuary and coastal waters. Finally, it will block the migration of important species of fish, especially shrimp, to important spawning and nursery grounds upstream of the Balingho site.
- Lake Balingho. Lake Balingho will inundate the floodplains from Balingho to Kuntaur, flooding up to 49 percent of the current rice land in The Gambia. The combined effect of evaporation and evapotranspiration might cause the water level of Lake Baligho to fall below its design minimum.
- Kekreti Dam and Lake Kekreti. The regulation of stream flow with Kekreti Dam will considerably reduce the annual flooding above Kuntaur. Dry season flow in the Gambia River from Kekreti to Kuntaur, however, will be considerably augmented. Although some recession rice production will be lost, fresh water will be available year-round. Lake Kekreti will flood primarily natural vegetation, but also 2,200 ha of agricultural land.
- Sedimentation. Although sediment will accumulate in the bolons, over a 100-year life span the reservoirs will be relatively unaffected.
- Groundwater supply. The reservoirs will increase the quantity of water in the shallow aquifers that supply water for rural populations.
- Wildlife. The potential impacts on wildlife will not pose a serious obstacle to development plans. Serious harmful impacts on wildlife will result from human activities rather than directly from development projects, assuming effective precautionary measures are taken during construction.

Impacts on Agricultural Production

Balingho Dam will affect current agricultural production. The loss of annual production due to flooding by Lake Balingho might not be made up by irrigation development for about ten years.

- Loss of rice production. About 18,000 tons of current rice production in The Gambia (in an average production year) will be lost annually due to flooding by Lake Balingho and associated impacts. About 1,000 tons will be lost to Lake Kekreti.
- Gain in rice production. With Kekreti only (Balingho delayed until irrigation agriculture is fully developed), annual rice production in The Gambia after ten years might be 20,000 to 30,000 tons higher than with both Kekreti and Balingho Dams -- if irrigation agriculture objectives can be met.

Constraints on Irrigation Agriculture

Anticipation of potential gains in irrigation agriculture production should be tempered because of the technical, administrative, and structural constraints to development on the scale envisioned. Furthermore, production gains will be constrained as households limit their participation in irrigation schemes because of what they see as the risks involved. In addition, irrigation models assume a greater availability of household labor than is likely to exist.

- Inefficient water delivery systems are a major constraint to double-cropping and proper crop husbandry.
- Member State governments do not presently have the capacity to train, supervise, and provision the number of agents necessary to achieve production goals.
- The existing marketing infrastructure is not equipped to handle the volume of current production.
- Limited transportation, storage, and communication facilities reduce the flexibility of the system to respond to production and input distribution requirements.
- Limited local storage and milling capacity create significant bottlenecks and increase marketing costs considerably.
- To support the management-intensive and capital-intensive irrigation schemes proposed, the Member State governments will have to pay significant and recurring subsidies.

Impacts on the Fisheries

The net result will be to diminish the production of the current marine and estuarine fisheries and create a productive reservoir fishery.

- Reservoir fisheries. The maximum total annual fish catch potential for the reservoirs is estimated to be 7,500 tons a year, provide there is effective fishery management. The breakdown will be: Lake Balingho, 5,600 tons; Lake Kekreti, 1,400 tons; Guinea lakes, 475 tons. The gross annual value of this fishery will be $7,500,000, although the net value will be considerably lower.
- Existing fisheries. Balingho will cause losses to the existing marine, shellfish, and estuarine fisheries in The Gambia with a value of upwards of $1,400,000 a year. The catch potential of Lake Balingho might offset the losses to the catch potential of the existing fisheries.
- Net annual value of Lake Kekreti and Guinea lake fisheries. The production of the reservoir fisheries on Lake Kekreti and the Guinea lakes will be a net gain, as current riverine fishery production is minimal. The net annual values will be: Lake Kekreti fishery, $881,000; Guinea lake fisheries, $274,000.
- Aquaculture potential. Development actions will create the potential for various types of aquaculture.

Impacts on People

The development projects will have different impacts on the peoples of the Member States. In The Gambia, the people will be extensively, indeed profoundly, affected by the construction of Balingho Dam and extensive expansion of irrigated agriculture. In Senegal Oriental, the people in the region of Kédougou and the Kekreti project will be significantly affected. In Guinea the people will not be as affected because the proposed dams are in remote and sparsely populated areas.

The construction of Balingho Dam and the expansion of irrigation agriculture will affect almost all of the persons in The Gambia outside of the Kombo districts. Persons from Tendaba to the eastern border past Fatoto will be affected, and many communities will suffer.

- Resettlement. Lake Balingho probably will require the resettlement of many persons, perhaps up to 15,000, because the lowland rice fields of numerous villages will be lost.
- Women. The loss of 15,000 ha of swamp rice to Lake Balingho will mean that thousands of women will lose their current productive role in the household.
- Out-migration. Lake Balingho could stimulate extensive out-migration of whole families and possibly whole communities, many to the Serekunda/Brikama region.

- In-migration. In addition to in-migration due to construction activities and employment, the formation of Lake Balingho will create a spontaneous in-migration of persons from other regions and countries. The new freshwater fishery on Lake Balingho will support 7,000 persons (fishermen and their families) if its potential is to be exploited.
- Urbanization. The Balingho area will become even more important commercially as a crossroads of water and land transportation. The construction settlement subsequently should become an important economic center.

The construction of Kekreti will disrupt the region because the road from Salemata to Kédougou will have to be rerouted and because portions of Salemata will be inundated. Regional marketing patterns will be disrupted.

- Resettlement. Lake Kekreti will require the resettlement of 8,000 to 18,000 persons.
- Construction settlement. A construction settlement of at least 2,000 persons will be formed at Kekreti. It should become a hub for regional development.
- In-migration. The region already attracts migrants from Guinea. The construction project and the man-made lake will intensify the in-migration of these and new peoples. The fishery will support 3,400 persons.
- Minorities. Construction of the dams at Kekreti and in Guinea will exacerbate interethnic tensions and place the Bassari, Bedik, Malinke, and Diallonke social fabrics at risk.

The construction of Kouya, Kankakoure, and Kogou Foulbe in Guinea will require two construction settlements, each of 2,000 persons, in sparsely populated areas.

The development projects will directly and indirectly improve transportation and navigation throughout the basin. This is essential to effective development of irrigation agriculture. In general, the multiplier effects of the development projects on socioeconomic infrastructures, although unmeasurable, will be important -- especially for The Gambia.

Impacts on Public Health

Experience has shown that the bringing together of persons for construction projects, the uprooting and resettling of persons, and in-migration and urbanization increase the transmission of diseases among humans in the short run. The

development projects, however, have the potential for improving public health in the long run. They provide the opportunity for improved water supply, sanitation, and health care services. Improvement in nutrition from reservoir fisheries and irrigation agriculture also will improve public health.

Despite these potential benefits, specific impacts on the prevalence of important diseases can be anticipated.

- The Gambia. Urinary schistosomiasis will become much more prevalent. Intestinal schistosomiasis, now hardly existent, will be established. The incidence of malaria will increase.
- Senegal. Urinary and intestinal schistosomiasis will become prevalent and perennial. The incidence of malaria will increase. The incidence of onchocerciasis will be slightly reduced.
- Guinea. The incidence of diseases will not be affected to a significant extent, except that some schistosomiasis will spread in association with irrigation from Kogou Foulbe.

Management and Mitigative Actions

Although some of the serious impacts of the development projects will be unavoidable, others will be amenable to various management and mitigative actions. The environmental, agricultural, and social impacts of Balingho Dam for the most part will be negative as well as not amenable to many mitigative measures. Anticipatory management before project implementation and during construction activities, however, can enhance some positive or potentially positive impacts of development. Mitigative measures, furthermore, will soften some of the negative impacts.

- Land and water management. Most of the impacts on land use and vegetation throughout the basin will be unavoidable, although some of the resources to be lost to inundation, such as firewood, can be exploited. Water quality can be maintained if mining activities are accompanied by strict environmental safeguards and irrigation systems are not constructed with free drainage access to the river. Wildlife can be protected if habitat is taken into consideration when project layout and activities are planned. It furthermore can be protected if strict safeguards are taken to prevent hunting and poaching. Niokolo-Koba National Park will be put in some jeopardy; so special precautions must be taken to preserve its integrity.

Special areas of concern should be to: i) educate and enlist the cooperation of local communities in natural resource management and conservation; ii) monitor water quality and set basinwide water quality standards; iii) prepare contour maps at 0.1 m intervals to determine impacts more precisely; iv) coordinate the control of water from Kekreti with downstream uses; and v) establish drawdown management policy to exploit the potential of the drawdown areas.

- Agricultural management. Agricultural management should recognize that rainfed agriculture will continue to be the basis of domestic food production until such time as the constraints to irrigated agriculture are eliminated. Investments in agriculture must be made both to improve the productivity of rainfed crops and to design irrigation models more suitable to the Gambia River Basin than those currently proposed. The potential benefits of agricultural management can be best realized if measures are taken to cope with constraints at the technical, administrative, structural, and household levels. The potential for foreshore farming is significant, and can be exploited with effective dam and reservoir management.

Special areas of concern should be to: i) establish a monitoring unit to collect agronomic and sociological data; ii) rehabilitate current irrigation projects; iii) adopt effective national agricultural policies to enhance agricultural productivity and encourage development of agricultural infrastructure; iv) strengthen agricultural research facilities; v) establish an agricultural extension agent training program; vi) improve marketing infrastructure; vii) include livestock considerations in development plans; and viii) improve transportation networks that support agriculture.

- Fishery and aquatic resource management. Preservation of existing fisheries and exploitation of potential reservoir fisheries will require careful planning and sustained management. The estuary must be protected from pollution to preserve its existing marine and shellfish fisheries. The reservoir fisheries will require extensive management infrastructure if the standing crops of fish are to reach their potential and if the fisheries are not to be overfished. The water quality of the reservoir must be maintained in the face of sedimentation, especially during the construction period, uncontrolled growth of aquatic weeds, and pollution from agricultural chemicals. A significant potential for increasing fishery production for both commercial and subsistence purposes is to introduce aquaculture into the reservoirs and the irrigation networks.

Specific areas of concern should be to: i) monitor the fish stocks and implement a program to manage the fish stocks; ii) formuate fishery policies to allocate resources to ensure maximum sustainable yields; and iii) develop the marine and estuarine fisheries, which currently are underexploited.

- Urban and regional planning. The combined impacts of construction and construction settlements, resettlement, migration, extensive irrigation projects, and new transportation systems will create an opportunity for coordinated regional planning, especially in Senegal Oriental. Resettlement planning can mitigate the disruptive effects of dislocation if agricultural, community, employment, and minority needs are taken into consideration. Resettlement communities can be planned in association with irrigation perimeters. In-migration can be anticipated and accommodated. Alternatives can be provided to minimize out-migration. Food assistance must be furnished during transition periods.

Special areas of concern should be to: i) commission a follow-up resettlement study for each dam and establish a resettlement monitoring unit to implement the recommendations of the studies; ii) ensure that OMVG and Member State agencies participate in construction planning and operations; iii) monitor and control in-migration to the construction sites and development regions; iv) take measures to stabilize rural populations during development periods; and v) establish land-use plans around the reservoirs and irrigation projects.

- Public health. Measures can be taken to control the transmission of schistosomiasis and malaria as well as other diseases, including sanitation measures, prevention and treatment of disease, and vector control. Safe water supplies must be provided. Health education should be undertaken. National health budgets can be increased.

Specifically, a health unit should be established within OMVG's technical staff to establish close liaison with the World Health Organization and the health ministeries of the Member States. Its responsibilities should be to: i) systematize collection and analysis of epidemiological statistics of the Member States; ii) initiate a long term program of health surveillance throughout the basin; and iii) participate in planning for the dams and irrigation projects.

- Basinwide policy. The Member State governments should develop basinwide environmental and public health policies, along with implementing legislation, to assist OMVG in guiding basinwide development. Our studies indicate a need

for legislation in regard to water control, environmental protection, wildlife and natural resource management, and fisheries management. OMVG should be charged with monitoring the aquatic and terrestrial environments, in cooperation with Member State agencies and with links to other West African institutions. An action plan for basin development should be accompanied by legislation of the Member State governments that would establish a basinwide environmental policy and provide for coordinated water resource management across national boundaries.

Benefits and Costs of Development Projects

Benefit/cost analyses of the Balingho and Kekreti projects separately and combined were conducted to estimate internal rates of return and net present values. Similar analyses were performed for irrigation agriculture. The results do not take into account certain unmeasured benefits and costs and are subject to modification by OMVG as additional information becomes available.

- Balingho Dam internal rate of return. The economic rate of return for Balingho Dam is 1.5 percent. Unmeasured costs would further reduce the rate of return, although multiplier effects would increase it.
- Kekreti Dam internal rate of return. The economic rate of return for Kekreti Dam is 9.2 percent. Unmeasured benefits would enhance the rate of return. However, a regional energy analysis is necessary.
- Balingho Dam and Kekreti Dam in tandem rate of return. The economic rate of return for the Balingho and Kekreti Dams together is 4.8 percent. This low rate of return is due to the negative influence of Balingho Dam.
- Irrigation agriculture rate of return. The economic rate of return for irrigation agriculture with a cropping intensity of 180 percent is 5.9 percent. The economic rate of return for irrigation agriculture with a cropping intensity of 120 percent is 1.1 percent.
- Net present value of Balingho Dam. The net present value of investment in the Balingho project is -$88,000,000.
- Net present value of Kekreti Dam. The net present value of investment in the Kekreti project is -$7,000,000.
- Net present value of Balingho Dam and Kekreti Dam in tandem. The net present value of the Balingho and Kekreti projects combined is -$95,000,000.

- Net present net value of irrigation agriculture. The net present value of irrigation agriculture with a cropping intensity of 180 percent is -$12,000,000. The net present value of irrigation agriculture with a cropping intensity of 120 percent is -$23,000,000.
- Sensitivity analysis assuming resettlement of 15,000 persons at Balingho. Under the assumption that resettlement of 15,000 persons is required at Balingho and with a discount rate of 10 percent, the internal rate of return becomes 1 percent and the net present value -$105,000,000.
- Sensitivity analysis assuming a discount rate of 6 percent. With a discount rate of 6 percent rather than 10 percent, the net present values become:

Balingho Dam	-$77,000,000
Kekreti Dam	+$42,000,000
Balingho Dam and Kekreti Dam	-$35,000,000

- Sensitivity analysis assuming a yield of 7.5 MT/ha. Under the assumption that the paddy rice yield for irrigation agriculture is 7.5 MT/ha per season rather than 4.5 and 4.0 MT/ha, the internal rates of return and net present values become:

  Irrigation (180%) 20.7% and $35,000,000
  Irrigation (120%) 12.1% and $ 7,000,000

Further Considerations

In the context of achieving overall self-sufficiency, OMVG and the Member States may be forced to make trade-offs between improving national balances of payments and achieving food self-sufficiency and even between increasing per capita income and promoting industrial development. Given finite resources, the implications of our studies for the objectives of improving balances of payments and achieving food self-sufficiency should be carefully examined.

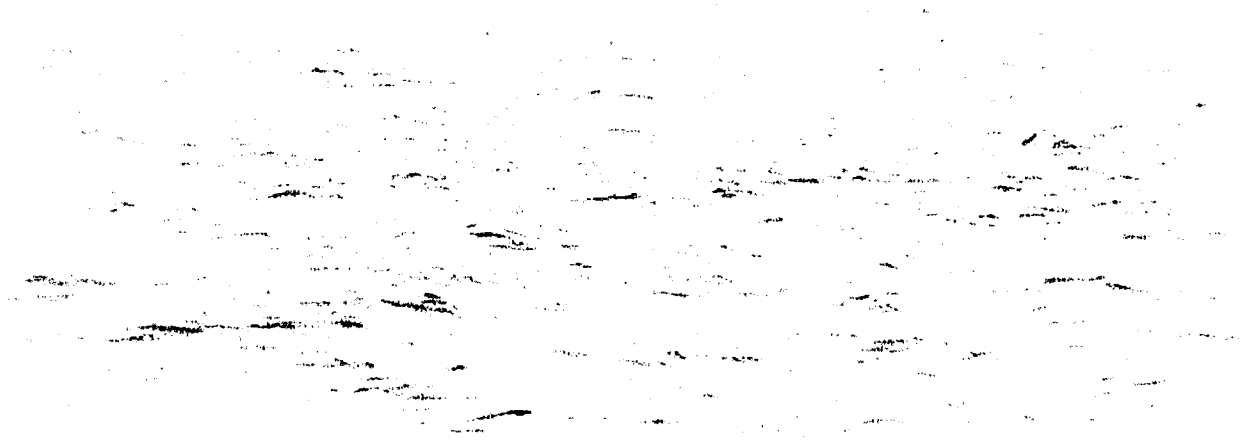
Our analyses suggest that expansion of large-scale irrigation in the near term, as called for in Gambia River Basin development plans, appears premature. Improvement of performance levels in existing schemes as well as the removal of constraints which limit increases in production of both irrigated and rainfed crops should be preconditions for further expansion. In essence, a development strategy committed solely to large-scale irrigation projects will encumber scarce resources that could be used to increase productivity in other agricultural sectors. Decision

makers therefore might consider a diverse portfolio of investment in agriculture in order to pursue food self-sufficiency with an optimal strategy.

Finally, insofar as the basic objectives of these Gambia River Basin studies are concerned, our analyses suggest that the association of the Balingho Project with the Kekreti project shoud be reevaluated. Member State decision makers should consider placing the construction of Balingho Dam after rather than before that of Kekreti Dam because of the potentially serious environmental and economic consequences of constructing Balingho. Construction of Kekreti Dam first would allow OMVG to pursue important development objectives while continuing to investigate the viability of Balingho Dam.

Above: Wharf at Tendaba, The Gambia, a fishing village about 15 km downstream from the proposed Balingho Dam site. Photo credit: Russell Moll.

Below: Representatives of OMVG discuss fishing techniques at Bansang, The Gambia. Traditional fishing canoes and nets are shown. Photo credit: Russell Moll.

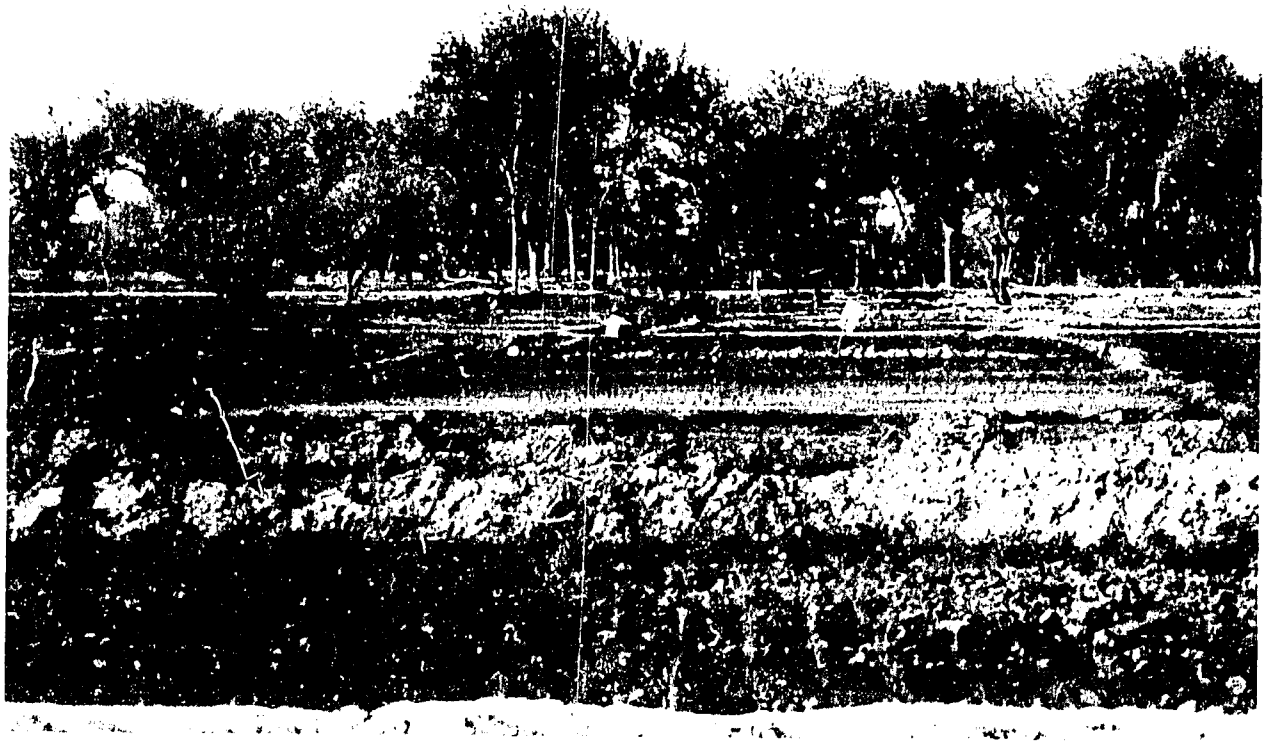


Above: An extensive Rhizophora mangrove forest. Photo credit: Russell Moll.

Below: Kundang Tenda, a typical Gambia River farming and fishing village. Photo credit: Russell Moll.

Above: Rice seedlings cultivated at Pakeba, Senegal. Photo credit: Frank Casey.

Below: PISO extension agent assisting with rice transplanting, Senegal. Photo credit: Frank Casey.



Above: Plots of transplanted rice at Pakeba, Senegal. Photo credit:Frank Casey.

Below: Fertilizer application on irrigated rice at Pakeba, Senegal. Photo credit : Frank Casey.

Above: Volcanic protrusion near Koundara, Guinea. Photo credit: Dario Rodriguez.
Below: Antelopes in Niokolo Koba National Park. Photo credit: Dario Rodriguez.

Above: Intrusion of agriculture into forest areas in The Gambia. Tree in right foreground has been slashed and burned at the base. Photo credit: Dario Rodriguez.

Below: Land cleared by fire on the outskirts of Termesse, Guinea. Photo credit: Dario Rodriguez.

Above: Forest cleared for agriculture near town of Mali, Guinea. Photo credit: Dario Rodriguez.
Below: Baobab and mango trees surrounding village of Boussoura, Guinea. Photo credit: Dario Rodriguez.

WATER RESOURCE MANAGEMENT
and
GAMBIA RIVER BASIN DEVELOPMENT

Page

PREFACE AND ACKNOWLEGEMENTS v

EXECUTIVE SUMMARY xi

LIST OF TABLES xxvii

LIST OF FIGURES xxix

LIST OF ACRONYMS AND ABBREVIATIONS xxxi

1. THE NEED FOR WATER RESOURCE MANAGEMENT 1

1.1. Basin Needs 5
1.2. Development Objectives 10
1.3. Basinwide Water Resource Development Problems. 13
1.4. Gambia River Basin Studies 20

2. DEVELOPMENT ACTIONS AND IMPACT NETWORKS 25

2.1. Management Actions and Interventions 27
2.2 Framework for Impact Analysis. 31

3. LAND AND WATER MANAGEMENT 41

3.1. Land and Water Management Impacts 43
3.2. Impacts in the Hydrosphere and Geosphere 53
3.3. Impacts on Land Use and Vegetation Patterns 61
3.4. Impacts on Socioeconomic Production 75
3.5. Impacts on Wildlife 80
3.6. Encouragement of Pest Species 83
3.7. Impact on Tourism 84

4. AGRICULTURAL MANAGEMENT 87

4.1. Management Requirements 87
4.2. Feasibility of Irrigation Agriculture Expansion 90
4.3. Irrigation Expansion Plans 91
4.4. History of Pump Irrigated Agriculture 93
4.5. Models for Irrigated Agricultural Development 95
4.6. Constraints to the Expansion of Irrigated Agriculture 98
4.7. Recurrent Cost and Subsidies 105
4.8. Agriucltural Management Options 107

5. FISHERY AND AQUATIC RESOURCE MANAGEMENT 111

5.1. Fishery and Aquatic Resource Management Impacts. 113

Page

5.2. Impacts in the Aquatic Biosphere 120
5.3. Impacts on the Fisheries 128

6. URBAN AND REGIONAL PLANNING 139

6.1. Urban and Regional Planning Impacts 141
6.2. Impacts on Settlements 147
6.3. Impacts on Socioeconomic Infrastructures 154
6.4. Sociocultural Impacts 158
6.5. Public Health 161

7. MANAGEMENT ACTIONS TO ENHANCE WATER RESOURCE DEVELOPMENT 179

7.1. Land and Water Management 179
7.2. Agricultural Management 183
7.3. Fishery and Aquatic Resource Management 187
7.4. Urban and Regional Planning 190
7.5. Public Health 193
7.6. Basinwide Policy 194

8. BENEFITS AND COSTS OF DEVELOPMENT PROJECTS 197

8.1. Framework for Analysis 197
8.2. The Economic Analyses Conducted 199
8.3. Benefit and Cost Factors of Dam Construction 201
8.4. Benefits and Costs of Expanded Irrigation Agriculture 209
8.5. Results of the Economic Analyses 211
8.6. Guinea Dams 216

9. FURTHER CONSIDERATIONS 217

BIBLIOGRAPHY 223

ANNEX A. University of Michigan Gambia River Basin Studies Working Documents 247

LIST OF TABLES

Table		Page
1.1.	Maximum Reservoir Surface Areas of Selected African Dams. . .	3
1.2.	Features of Proposed Gambia River Basin Dams and Reservoirs . .	4
2.1.	Management Actions and Interventions	32
2.2.	Primary Management Networks.	33
3.1.	Land and Water Management Impact Attributes.	46
3.2.	Seasonal Variation in Reservoir Surface Areas and Depths	55
3.3.	Current Land Use and Vegetation Cover in the Gambia River Basin	65
3.4.	Land Use and Vegetation Cover Flooded by Reservoirs.	67
3.5.	Loss of Land Use and Vegetation Cover Losses Directly Due to Construction Activities	70
3.6.	Proposed Irrigation Agriculture Development.	74
3.7.	Current Land Use of Areas Identified for Irrigation Development .	74
3.8.	Loss of Agriculture Due to Development.	76
3.9.	Losses of Natural Resources Due to Reservoirs and Dam Infrastructure Construction.	81
4.1.	Agricultural Management Attributes	89
4.2.	Model Assumptions and Characteristics	97
4.3.	Investigation, Operation and Maintenance Costs of Irrigation Models.	106
4.4.	Production Input Subsidies During the Dry Season, 1983/84	108
5.1.	Fishery and Aquatic Resource Management Impact Attributes . .	115
5.2.	Estimates of Annual Fish Catch Potential for Gambia River System Reservoirs	130
5.3.	Estimated Fishery Catch in The Gambia	132
5.4.	Estimated Value of Catch Losses Due to Balingho Dam.	134
5.5.	Benefit/Cost of Kekreti and Guinea Reservoir Fisheries	136

Table		Page
6.1.	Urban and Regional Planning Attributes	144
6.2.	Minimum Populations Necessary to Exploit Fishery Potential	153
6.3.	Perimeters of the New Man-Made Lakes	153
6.4.	Management Actions and Environmental Attributes to Assess Impacts on Disease Vectors	163
6.5.	Qualitative Assessment of Construction Stage Impacts on Disease Vector Populations	165
6.6.	Qualitative Assessment of Short-Term (< 5 Years) Impacts on Disease Vector Populations	166
6.7.	Qualitative Assessment of Long-Term Operational Stage Impacts on Disease Vector Populations	167
6.8.	Impacts on Major Diseases	168
6.9.	Impacts on Other Diseases	172
6.10.	Costs of Public Health Mitigative Measures	175
8.1.	Economic Rate of Return for Development Projects	212
8.2.	Net Present Value for Devlopment Projects	212
8.3.	Economic Rate of Return for Balingho and Kekreti Combination	214

LIST OF FIGURES

Figure	Page
1.1. Development Projects Proposed for The Gambia River Basin	2
1.2. Population Projections for the Gambia River Basin	6
1.3. Flow of the Gambia River at Gouloumbou, The Gambia, 1953 to 1982	9
1.4. Primary Gambia River Basin Development Objectives	11
1.5. Cereal Production and Demand (Without Wheat) in the Gambia River Basin	12
1.6. The Ecosystem of the Gambia River Basin With Its Six Interlinked Functional Subsystems	15
1.7. A Management Action in One Subsystem Affects Elements in Other Subsystems	16
2.1. Interrelationships of Development Actions and Ecological Subsystems of the Gambia River Basin	26
2.2. Development and Management Actions for Gambia River Basin Development	28
2.3. Sequence of Actions and Impacts in a Management Network	30
3.1. Land and Water Management Network	42
3.2. Land Use Tradeoffs of Basinwide Development	45
3.3. Balingho Reservoir Surface Area Representation	48
3.4. Kekreti Reservoir Surface Area Representation	49
3.5. Kankakoure Reservoir (Upper) and Kouya Reservoir (Lower) Surface Area Representation	50
3.6. Kogou Foulbe Reservoir Surface Area Representation	51
3.7. Impact of Reservoirs on Water Surface Area in the Gambia River Basin	55
3.8. Land Use and Vegetation Cover in the Gambia River Basin	64
3.9. Land Use and Vegetation Cover by Countries in the Gambia River Basin	66

Figure		Page

3.10. Impact of Balingho Reservoir on Gambian Rice Production with Irrigation Development 78

4.1. Agricultural Management Network. 88

5.1. Fishery and Aquatic Resource Management Network 112

5.2. Fishery Tradeoffs of Basinwide Development 114

5.3. Modification of Water Resource Map by Development Actions . . 117

5.4. Aquatic Biosphere Impact Network. 121

6.1. Urban and Regional Planning Network 140

6.2. Socioeconomic and Sociocultural Tradeoffs of Basinwide Development 142

6.3. The Dam at Balingho will Encourage the Breeding of the Malaria Vector, A. funestus 170

LIST OF ACRONYMS AND ABBREVIATIONS

AHT	Agrar-und Hydrotechnik GMBH
CRED	Center for Research on Economic Development
GPMB	Gambia Produce Marketing Board
GRBS	Gambia River Basin Studies
HHL	Howard Humphreys Limited
LRDC	Land Reclamation and Development Consultants
OFADEC	Office Africain pour le Développement et la Coopération
OMVG	Gambia River Basin Development Organisation
OMVS	Organisation pour la Mise en Valeur du Fleuve Sénégal
PISO	Périmètres Irrigués du Sénégal-Oriental
RBDO	River Basin Development Office
SAED	Société d'Aménagement et d'Exploitation des Terres du Delta du Fleuve Sénégal
SIES	Société Industrielle d'Engrais au Sénégal
SODEFITEX	Société de Développement des Fibres Textiles
USAID	United States Agency for International Development

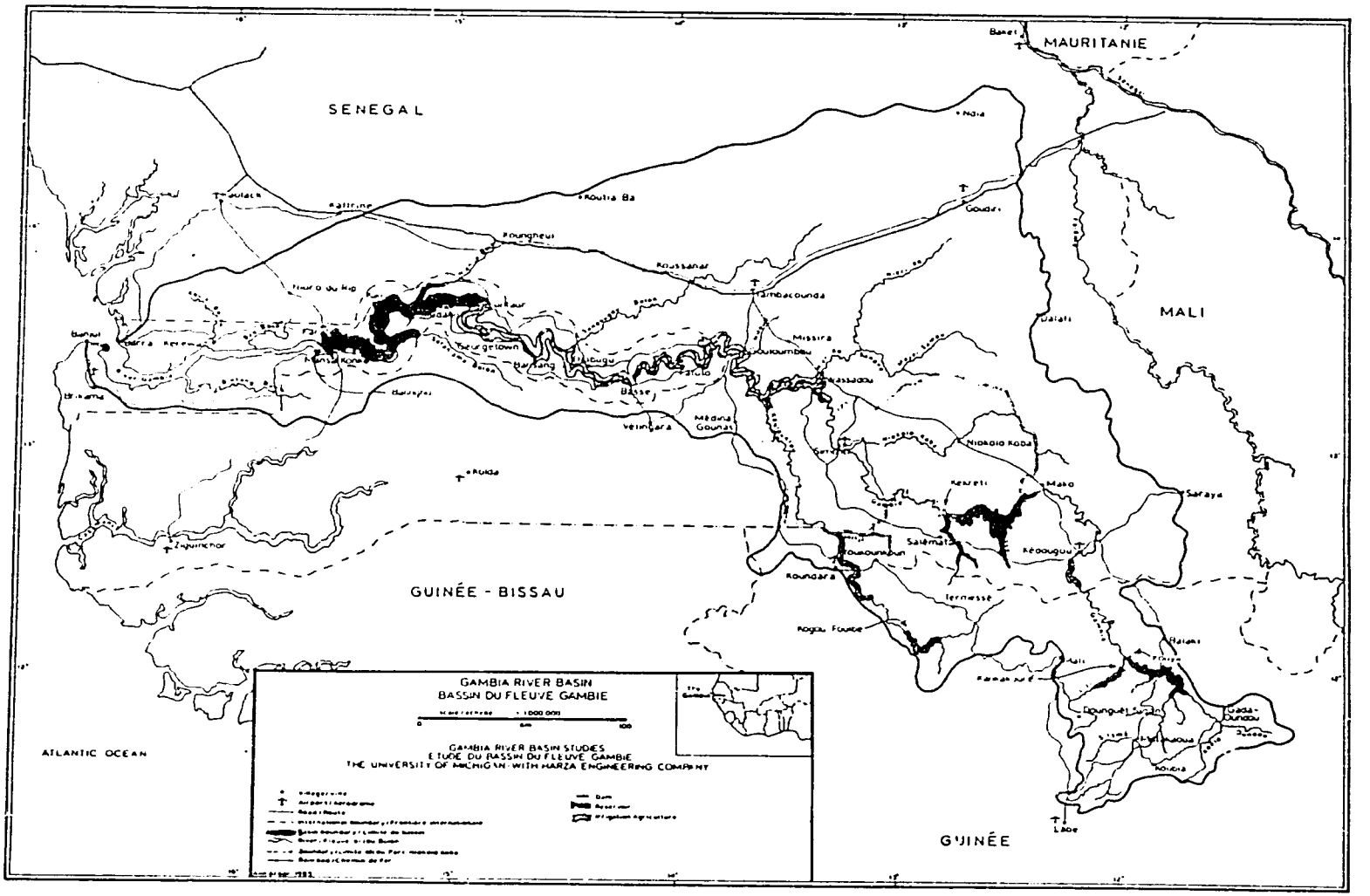
1. THE NEED FOR WATER RESOURCE MANAGEMENT

Development of the water resources of the Gambia River Basin provides The Gambia, Guinea, and Senegal with an excellent opportunity for improving their economies and for increasing the well-being of their citizens. Even with careful planning, however, river basin development disrupts the environment. It furthermore disrupts the social structures and the lives of the people who are to benefit from the component projects.

Environmental and socioeconomic studies of the Gambia River Basin were therefore initiated and funded by the United States Agency for International Development (USAID) through its River Basin Development Office (RBDO) in Dakar, Senegal. These studies were undertaken to analyze the impacts of specific water resource development projects proposed for the watershed by the Gambia River Basin Development Organisation (OMVG) and the four Member States -- The Gambia, Guinea, Guinea-Bissau, and Senegal. They were contracted to the University of Michigan Center for Research on Economic Development (CRED), with assistance from Harza Engineering Company of Chicago, Illinois. The results of the studies, as reported here, will be used by OMVG and the Member States as they proceed with development of the Gambia River Basin.

These studies investigated the socioeconomic and environmental implications of plans for construction of five dams in the Gambia River system -- Balingho in The Gambia, Kekreti in Senegal, and Kouya, Kankakoure, and Kogou Foulbe in Guinea -- as well as for significant expansion of irrigation agriculture in the basin. Construction of the dams represents a coordinated set of hydroelectric, irrigation, and water control projects which will have impacts throughout the basin (Figure 1.1.). Relative to other African dams (Table 1.1.), Balingho, Kekreti and Kouya on the Gambia River will have large reservoir surface areas, ranging from 101 km^2 to 716 km^2. Of the 231 existing reservoirs in Africa, only 8 have more than 1000 km^2 maximum reservoir surface area and only 32 have more than 100 km^2 maximum reservoir surface area. Thus, Balingho, Kekreti, and Kouya will rank in the top 15% of reservoirs in Africa in this respect. Kankakoure and Kogou Foulbe are on tributaries and are relatively small.

The five dams form projects that will have both significant impact and considerable development potential (Table 1.2.) These dams will create man-made lakes with a total maximum surface area of 1200 km^2 and a total maximum



University of Michigan Gambia River Basin Studies, 1985.

Figure 1.1. Development Projects Proposed for The Gambia River Basin

Table 1.1. Maximum Reservoir Surface Areas of Selected African Dams.

Reservoir	Country	Maximum Surface Area
32 reservoirs		Range: 8270 km² to 113 km²
Volta	Ghana	8,270 km²
Kariba	Zimbabwe/Zambia	5,550 km²
Kainji	Nigeria	1,260 km²
Buyo	Ivory Coast	900 km²
Balingho*	The Gambia	716 km²
Manantali	Mali	477 km²
Diama	Senegal/Mauritania	440 km²
Kekreti*	Senegal	338 km²
Tiga	Nigeria	178 km²
Tokwe Mokorsi	Zimbabwe	113 km²
Kouya*	Guinea	101 km²
54 existing reservoirs		91 km² to 10 km²
104 existing reservoirs		9.9 km² to 1 km²
41 existing reservoirs		less than 1 km²

* Proposed

Sources: Dam design and operation to optimize fish production in impounded river basins, G.M. Bernacsek, FAO/CIFA Technical Paper 11, FAO, Rome 1984, except for Diama and Manantali, which are from Assessment of Environmental Effects of Proposed Developments in the Senegal River Basin, Final Report, Gannett Fleming Corddry and Carpenter and ORGATEC Société African d'Etudes Techniques for Organisation pour la Mise en Valeur du Fleuve Sénégal, n.d.

Table 1.2. Features of Proposed Gambia River Basin Dams and Reservoirs.

Features	Dams and Reservoirs					
	Gambia River			Tributaries (Guinea)		Total
	Balingho (The Gambia)	Kekreti (Senegal)	Kouya (Guinea)	Kankakouré (Liti)	Kogou–Foulbe (Koulountou)	
River km from Mouth	km 128	km 790	km 1034	km 1038	km 764	
Reservoir Maximum Volume	1.4 km^3	3.5 km^3	4.27 km^3	.13 km^3	.45 km^3	9.75 km^3
Reservoir Maximum Surface Area	716 km^2	338 km^2	101 km^2	8.3 km^2	38 km^2	1201.3 km^2
Hydroelectric Generator Capacity	0	48 MW	85.5 MW	36 MW	4.9 MW	174.4 MW
Irrigation Potential	5000 ha*	70,000 ha	3000 ha	---	12,000 ha	85,000 ha
Reservoir Fishery Potential	6325 tons/yr	2176 tons/yr	265 tons/yr	34 tons/yr	177 tons/yr	8977 tons/yr
Persons to be Resettled	0–15000	8000–18000	>600	>400	0	9000–34000 persons

* without Kekreti
--- unknown

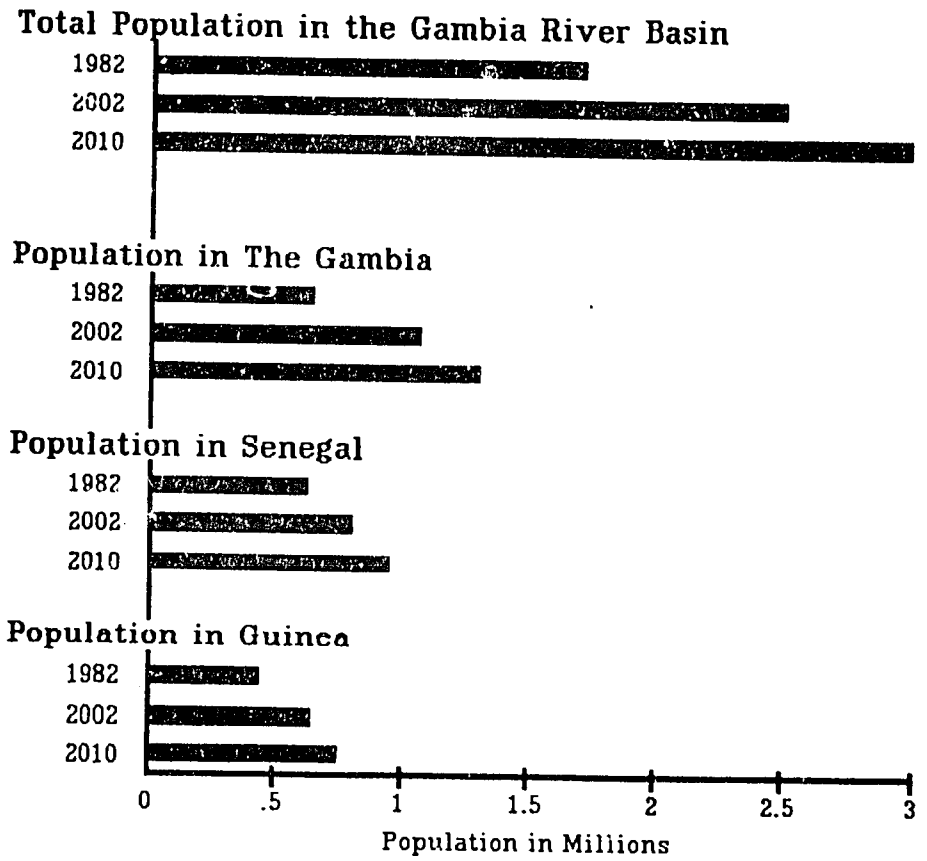
University of Michigan Gambia River Basin Studies, 1985.

volume of 9.75 km^3. The dams will enable the flow of the Gambia River to be controlled for development purposes. Specifically, management of this important water resource is planned to enable irrigated agriculture in the basin to be significantly expanded -- perhaps up to 85,000 ha from the 3,000 ha currently cultivable under irrigation. Furthermore, it will provide 174.4 megawatts (MW) of hydroelectric power capacity to enable agricultural and industrial development without increasing oil import requirements. It also will make fresh water available year-round for human and animal consumption as well as, with Balingho, eliminate the salinity of the river for some 120 km upstream from the proposed site for the dam.

1.1. Basin Needs

The development of the Gambia River Basin is being planned to meet critical economic, nutritional, and social needs. In general, the basin is characterized by low rural incomes, insufficient nutrition and, in most regions, dependence on considerable grain imports and food aid, according to the OMVG Draft Indicative Plan for the Integrated Development of the Gambia River Basin. In 1982, for example, rural per capita income in the basin was $112 in The Gambia, $121 in Guinea, and $200 in Senegal. Caloric needs were not sufficiently met in The Gambia (perhaps 95% of the needs were satisfied) or in Guinea (perhaps 81% of the needs were satisfied). The Gambia produced only 58% of the cereal it consumed, and each of the countries had to divert scarce foreign exchange to import considerable quantities of grain and other food. The Gambia had a deficit of 56,000 tons in cereal production, while the basin portions of Guinea and Senegal were assumed to be about self-sufficient (Guinea and Senegal as a whole had serious deficits in grain production).

The needs in the basin are increasing in severity because of population growth (Figure 1.2.). The population of The Gambia is projected to increase from about 630,000 in 1982 to 1,300,000 in 2010 -- a 100% increase in just 28 years (assuming a slow rate of population growth). The population in the Senegal portion of the basin is projected to increase from 600,000 in 1982 to 940,000 in 2010, a 53% increase, and in the Guinean portion from 440,000 to 726,000, a 70% increase. These population projections may be conservative but, even if they turn out to be accurate, the food needs of the basin population will become extremely critical.



Population projections assume average annual growth rate of 2.1 to 2.5%.

Source: OMVG Draft Indicative Plan for the Integrated Development of The Gambia River Basin.

University of Michigan Gambia River Basin Studies, 1985.

Figure 1.2. Population Projections for the Gambia River Basin.

Without basin development, especially in the agricultural sector, the economic and nutritional deficiencies in the basin could be almost catastrophic. Economically, the countries will not be able to sustain the levels of food imports that will be required to maintain current consumption patterns.

The population increase will cause other situations in the basin to deteriorate. Unemployment will increase significantly, especially in the absence of industry in the basin. There is little manufacturing outside of the Banjul-Kanifing area -- limited to such industries as textile mills at Kau-ur and Kuntaur, and bonga drying and hide drying operations at Kuntaur -- other than artisanal and domestic crafts. There also is virtually no mining, despite known mineral deposits in Guinea and Senegal Oriental. Fossil fuel imports will increase, along with virtually all manufactured goods in The Gambia and Guinea. The result will be to make already serious problems of foreign exchange even more severe.

Problems in other areas will worsen as well. At present, education, health care, and technical services are seriously inadequate. They will become more so as economic and nutritional problems worsen. The prevalence of illiteracy prevents the agrarian population from taking advantage of government socioeconomic services and improved agricultural technologies. In general, agricultural technology still is traditional and produces low yields. In addition, breakdowns in government support services are a serious problem. Next to the lack of rainfall, farmers report that their greatest problems are: the lack of timely availability of credit, seeds, and fertilizer; breakdowns and delays in fueling, repair, and replacement of existing irrigation pumps; and delays in payment for cash crops delivered to purchasers and agencies.

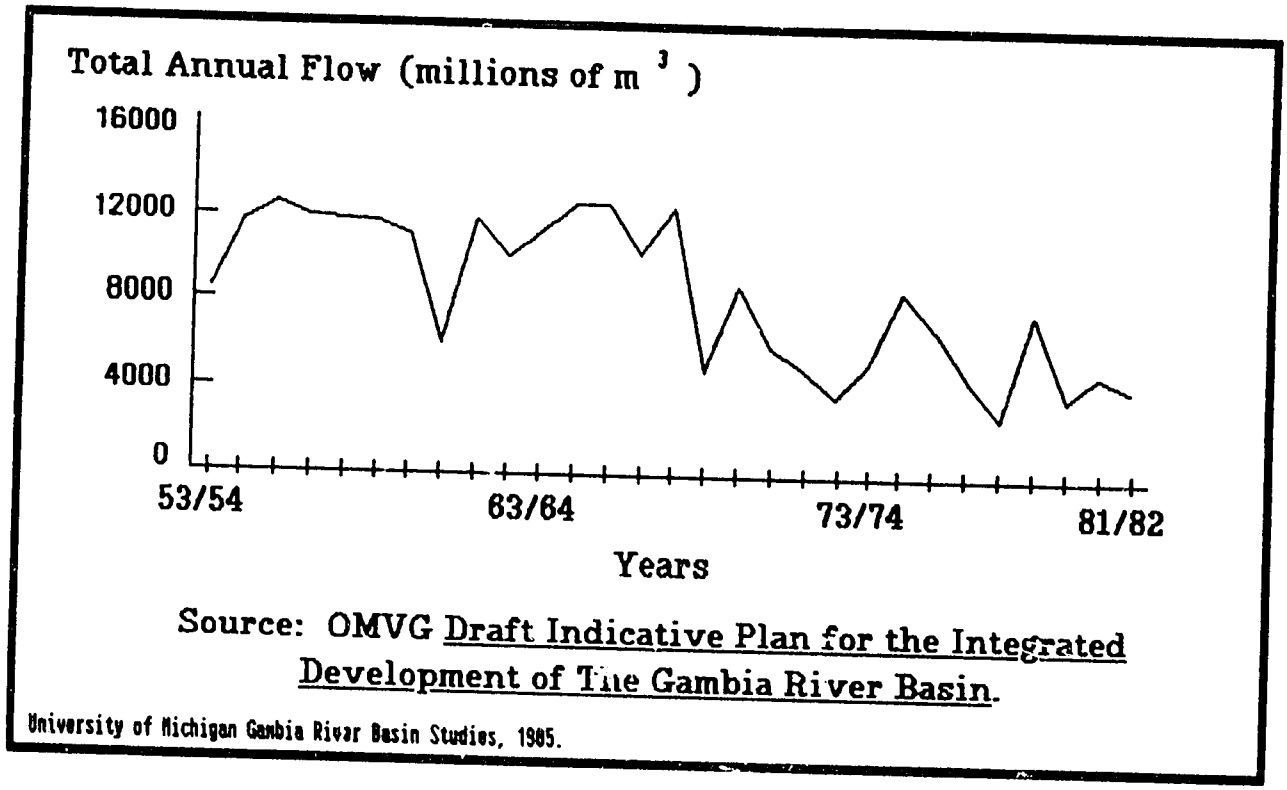
Environmental problems in the basin compound the situation. There is a serious shortage of wood in The Gambia and Guinea, and severe degradation of forest lands throughout the basin. The pressing need for grain has led to overcropping of the fields being worked, so the lack of fallowing the land inevitably will lead to degradation of the soil and further lack of productivity. The cropping also is encroaching on grazing and forest lands, and conflicts arise among competing uses. In the past 25 years, the basin has experienced a dramatic increase in the exploitation of wetlands, uplands, and forest resources.

Public health problems already are severe. The three major West African water-associated diseases, which might contribute to large-scale negative health impacts in the event of dam construction on the Gambia River, already pose serious

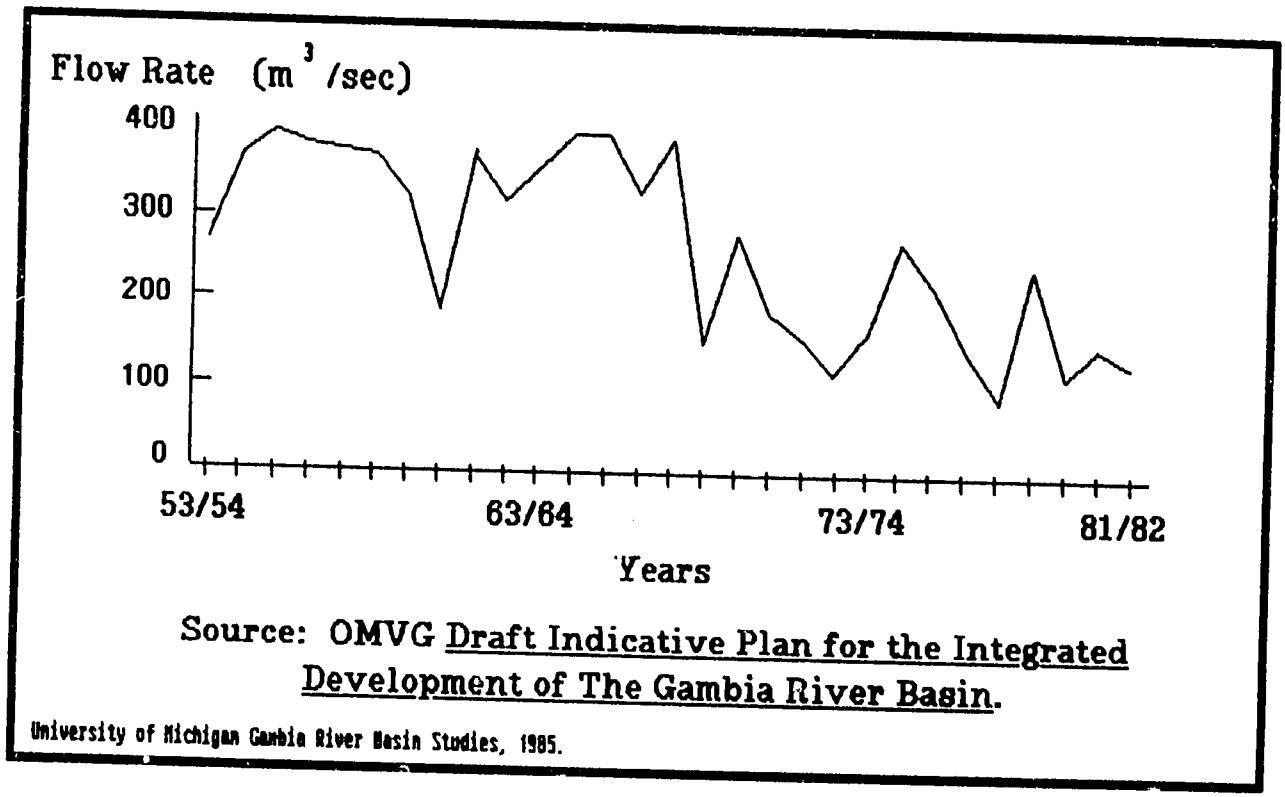
health problems in the basin. Malaria, combined with poor nutrition, now contributes to a death rate of almost 450 per 1,000 children under 5 years of age in areas of rural West Africa. Although malaria control is practiced in some urban areas, rural areas rarely, if ever, experience control efforts. Urinary schistosomiasis in The Gambia, Senegal Oriental, and the Koulountou Basin of Guinea is currently limited by increasingly severe annual drought conditions and is not associated with the main rivers. However, with settlement at the edges of reservoirs and with considerable expansion of irrigation, patterns of transmission will change and many new human cases will occur. The reservoir will also permit many new cases of intestinal schistosomiasis, which at present has a low incidence in the basin. Because of its insidious and chronic nature, schistosomiasis tends to receive little attention from authorities and is addressed, if at all, by ad hoc research programs. Onchocerciasis (river blindness) will continue to plague areas of the basin, as most of the vector blackfly breeding regions are outside of the proposed impoundments. Currently, onchocerciasis control is not attempted by central health authorities in Senegal or Guinea (the disease does not occur in The Gambia). An area in Senegal Oriental has the highest rate of infection in West Africa (60% to 80% of the population affected, with a 15% rate of blindness).

Finally, there are the recurrent droughts or low annual rainfalls of the past fifteen years, in which the mean flows of the Gambia River from 1953 to 1982 have been significantly reduced (Figure 1.3.). At Gouloumbou in The Gambia (which separates the "maritime" and "continental" zones of the Gambia Basin), the mean annual discharge from 1970/71 to 1981/82 was only 168 m^3/sec, whereas from 1953/54 to 1969/70 it had been 329 m^3/sec. One result has been to allow saltwater intrusion as far as 250 km upstream (beyond Kuntaur) in the dry season. The complete failure of swamp rice downstream from Farafenni in 1983 was due to the late retreat of the saltwater and its early return before the rice had flowered. Throughout the basin, the drought increasingly is reducing agricultural production at a time when its increase is sorely needed.

The situation has become critical. Extensive Gambia River Basin development is necessary to meet these increasing needs. Fundamental to most development projects is effective water resource management in the basin.



A. Total Annual Flow



B. Average Flow Rate

Figure 1.3. Flow of the Gambia River at Gouloumbou, The Gambia, 1953 to 1982.

1.2. Development Objectives

The overall objective of Gambia River Basin Development is to better "the lives of the people in the basin," according to the OMVG Draft Indicative Plan. Specifically, this involves:

- achieving food self-sufficiency
- increasing per capita income
- promoting industrial development
- improving national balances of payments
- enhancing the quality of life
- preserving environmental quality

Although achieving food self-sufficiency is a primary objective, this also would contribute to achievement of other objectives (Figure 1.4.) such as increasing per capita income and improving national balances of payments. Achieving these objectives, furthermore, will require that additional objectives be attained as well. Improvement of water and land transportation systems, for example, will be required to support agricultural development on the scale envisioned. Exploitation of the mineral resources in the basin, favored by hydroelectric power, could considerably improve the national balances of payments. Development of the Gambia River Basin, therefore, involves pursuit of a coordinated and indeed integrated set of objectives.

Achievement of food self-sufficiency provides the impetus for basin development because of the projected deficiencies in cereal production (Figure 1.5.). Present cereal production is insufficient to meet consumption needs in most of the basin except some regions of Senegal. (Our field studies suggest that even in Senegal Oriental production is barely able, if not insufficient, to meet the needs.) Yet conservative population projections indicate that the demand for cereal in The Gambia may grow from 109,000 tons to 260,000 tons by 2010 -- whereas current production is only 78,000 tons. Demand in the Senegal portion of the basin may grow to 205,000 tons, whereas current production is only 160,000 tons; demand in the Guinean portion of the basin may grow to 116,000 tons, whereas current production is only 78,000 tons.

When the proposed irrigation and related agricultural projects are realized, perhaps 50,000 hectares will have been added to the existing agricultural base (almost all of which is rainfed agriculture). Significant increases in yield are

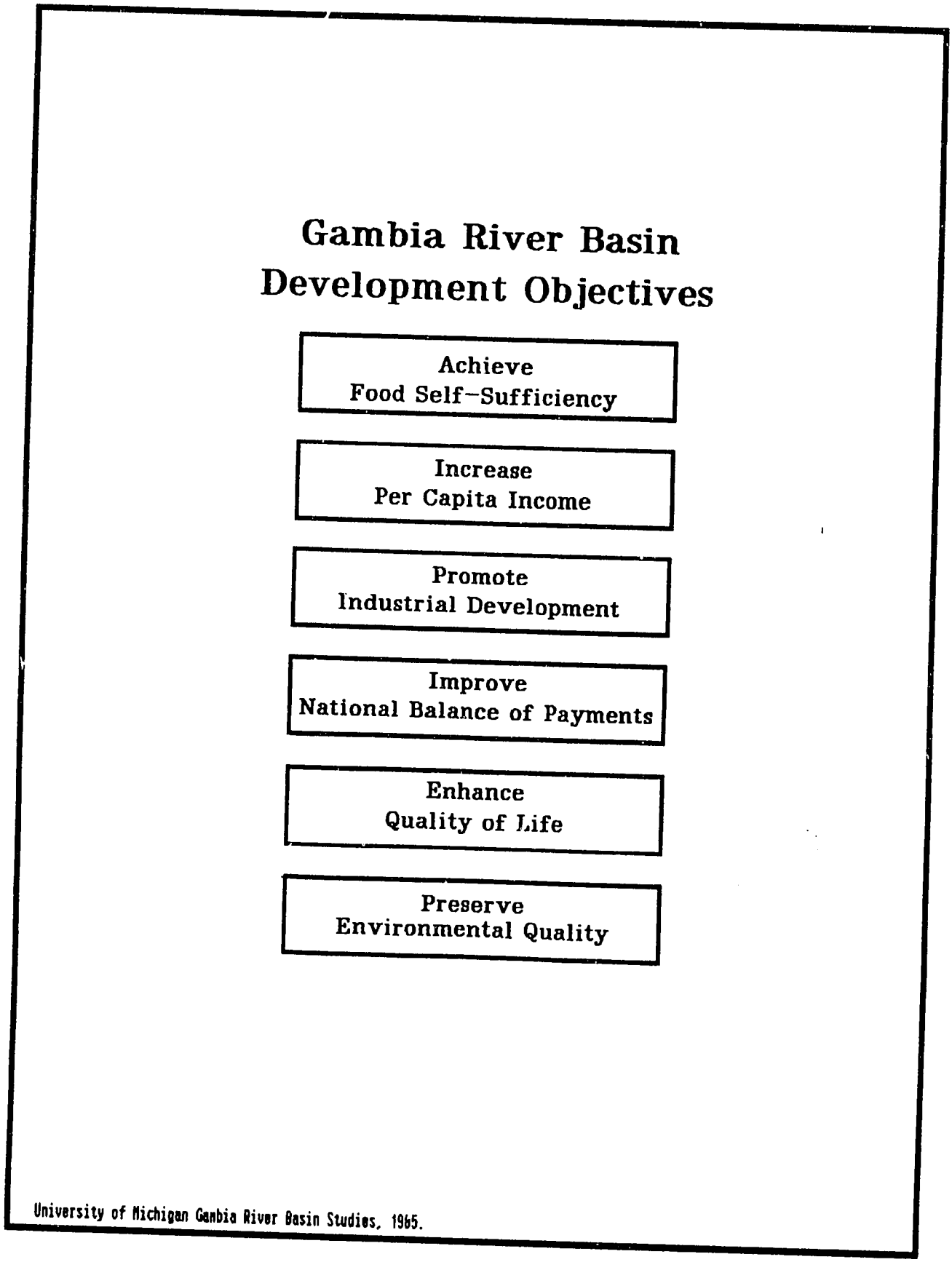
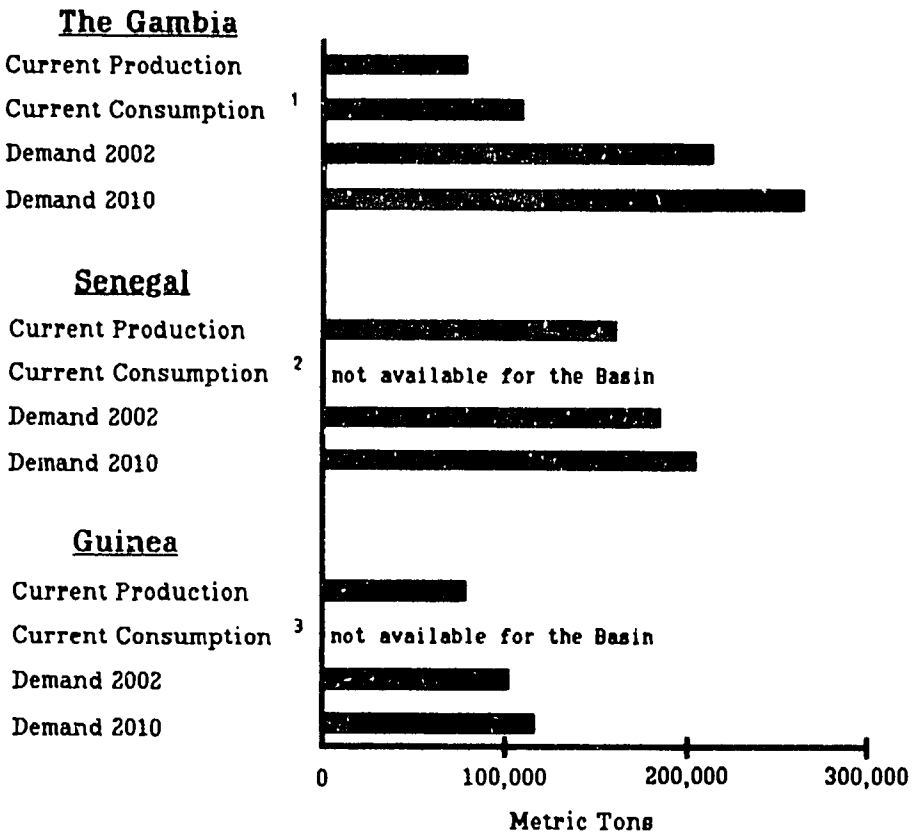


Figure 1.4. Primary Gambia River Basin Development Objectives.



1 - 95% of average daily caloric needs (from all sources, including imported wheat)

2 - 99% of average daily caloric needs (from all sources, including imported wheat)

3 - 81% of average daily caloric needs (from all sources, including imported wheat)

All demand projections are for low population growth rate projections

Source: OMVG Draft Indicative Plan for the Integrated Development of the Gambia River Basin.

University of Michigan Gambia River Basin Studies, 1985.

Figure 1.5. Cereal Production and Demand (Without Wheat) in the Gambia River Basin.

envisioned with a change from rainfed, traditional agriculture to irrigated, technology-supported agriculture. The Draft Indicative Plan concludes that, given the projected needs in the basin, the "goal of food self-sufficiency" cannot be met through improvement of rainfed agriculture alone. With irrigation agriculture, in part enabled by the construction of dams to store water for irrigation purposes, the hope is to achieve basinwide food self-sufficiency in perhaps 20 or 30 years.

Additional objectives for development of the Gambia River Basin involve further exploitation and management of its natural resources. Of particular importance for food self-sufficiency is to enhance fishery and livestock production, which depend on the water, land, and vegetation resources available for use. Of additional importance for economic objectives is to exploit the resources available for timber, firewood, minerals, and ores as well as to improve the transportation and marketing infrastructures. These will enable the development of industries associated with agriculture, fishery, forestry, and mining activities. In order to enhance the quality of life of the people in the basin, public health, sanitation, water supply, and other community services must be improved.

Pursuit of these various objectives for development of the Gambia River Basin requires effective planning, coordination, management, and funding. Thus, a primary corollary development objective is to enhance the capabilities of the OMVG (Gambia River Basin Development Organisation) as a basinwide administrative institution. This objective is particularly important to the Member State governments who will rely on the OMVG to coordinate development efforts as well as on donor agencies to fund the dams and hydroelectric projects in addition to many of the irrigation and other developmental activities. The OMVG, an international organization of the four Member States with territory in the Gambia River Basin (The Gambia, Guinea, Guinea-Bissau, and Senegal) has as its charge "to centralize the administrative task of developing and apportioning the waters of the Gambia River and of promoting projects that can increase production and productivity in agriculture, livestock, forestry and mining," according to the Draft Indicative Plan. The OMVG is undertaking to develop the fisheries as well.

1.3. Basinwide Water Resource Development Problems

Development objectives for the Gambia River Basin address the pressing needs of its human populations. Insofar as these require integrated development of the water resources of the basin, primarily the construction of dams to furnish water for

irrigation, hydroelectric power, and regulated freshwater flow, in meeting these objectives the OMVG and associated institutions will encounter serious problems, some of which may be insurmountable. In essence, difficult decisions and tradeoffs must be made.

Planners of integrated development of river basins undertake a task with many unknowns, even after extensive socioeconomic and environmental studies have been made and a variety of alternative development scenarios analyzed with considerable care. Based on global experience, the unknowns hide significant dangers that inevitably emerge. The unknowns also hide many secondary costs of improving and mitigating changes in social and economic institutions as well as in environmental areas. These impacts and costs are difficult to anticipate because of the interrelationships among innumerable social and environmental factors.

The Gambia River Basin is a complex ecosystem which consists of six interrelated subsystems (Figure 1.6.):

- the atmosphere
- the hydrosphere
- the geosphere
- the aquatic biosphere
- the terrestrial biosphere
- human culture

The atmosphere, hydrosphere, and geosphere -- air, water, and land -- are the physical systems of the ecosystem. The aquatic biosphere and the terrestrial biosphere are the biological production systems that depend on and interact with the physical systems. Human culture depends on and interacts with both the physical and the biological systems. For the purposes of our study, we have divided human culture into socioeconomic production, socioeconomic infrastructure, sociocultural institutions, and public health components.

The significant characteristic of the ecosystem is that the six subsystems are linked to each other (Figure 1.7.), although of course they simultaneously are somewhat independent interrelated systems at their own levels. Thus, human actions or "interventions" in one subsystem affect elements in other subsystems through what ecologists call "functional energy transfer mechanisms." Thus, any water management activity can impact all six subsystems, including that of human socioeconomics and culture. For example, a management action in the hydrosphere such as regulation of downstream flow, which is one objective of constructing dams

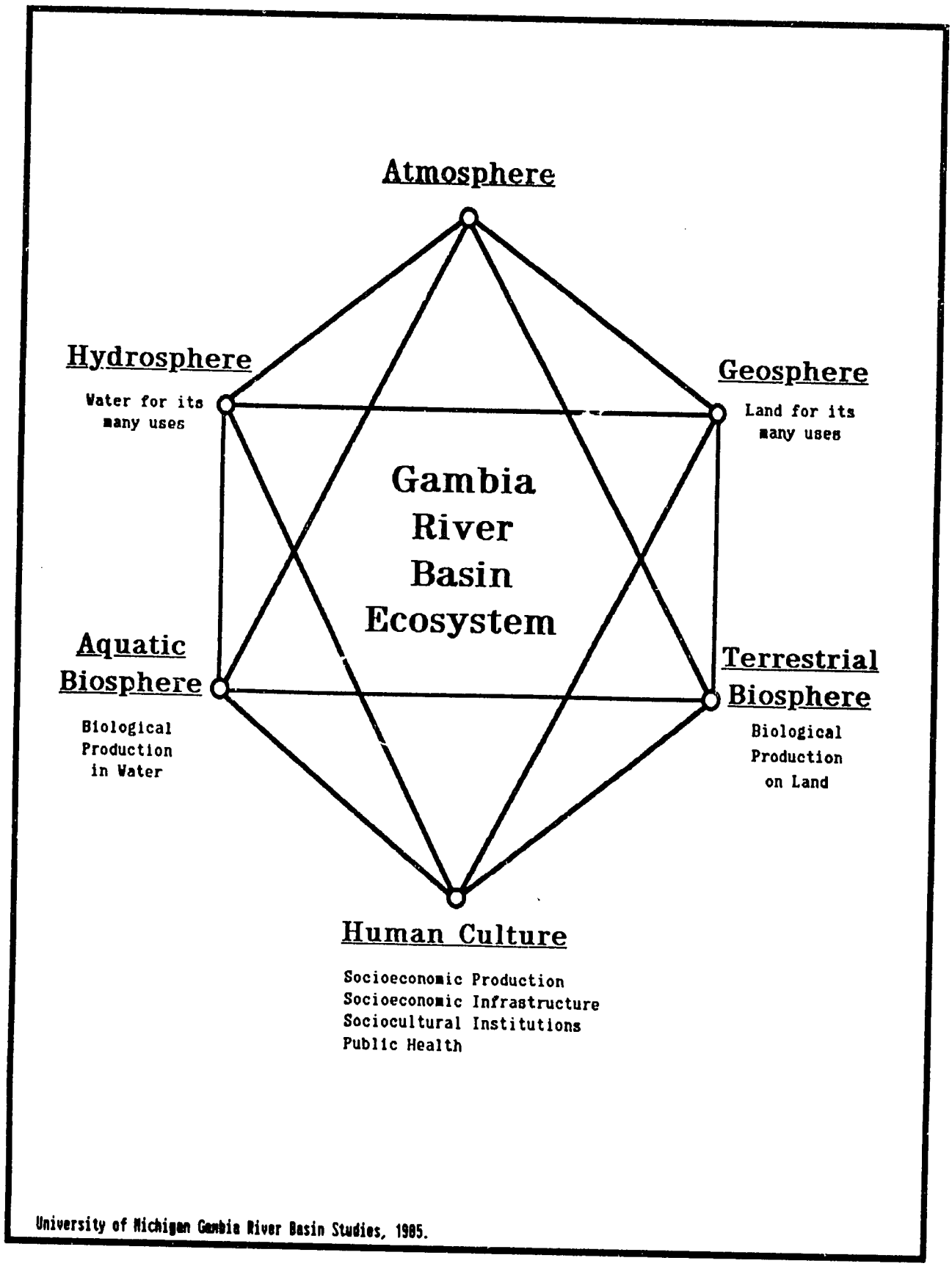


Figure 1.6. The Ecosystem of the Gambia River Basin With Its Six Interlinked Functional Subsystems.

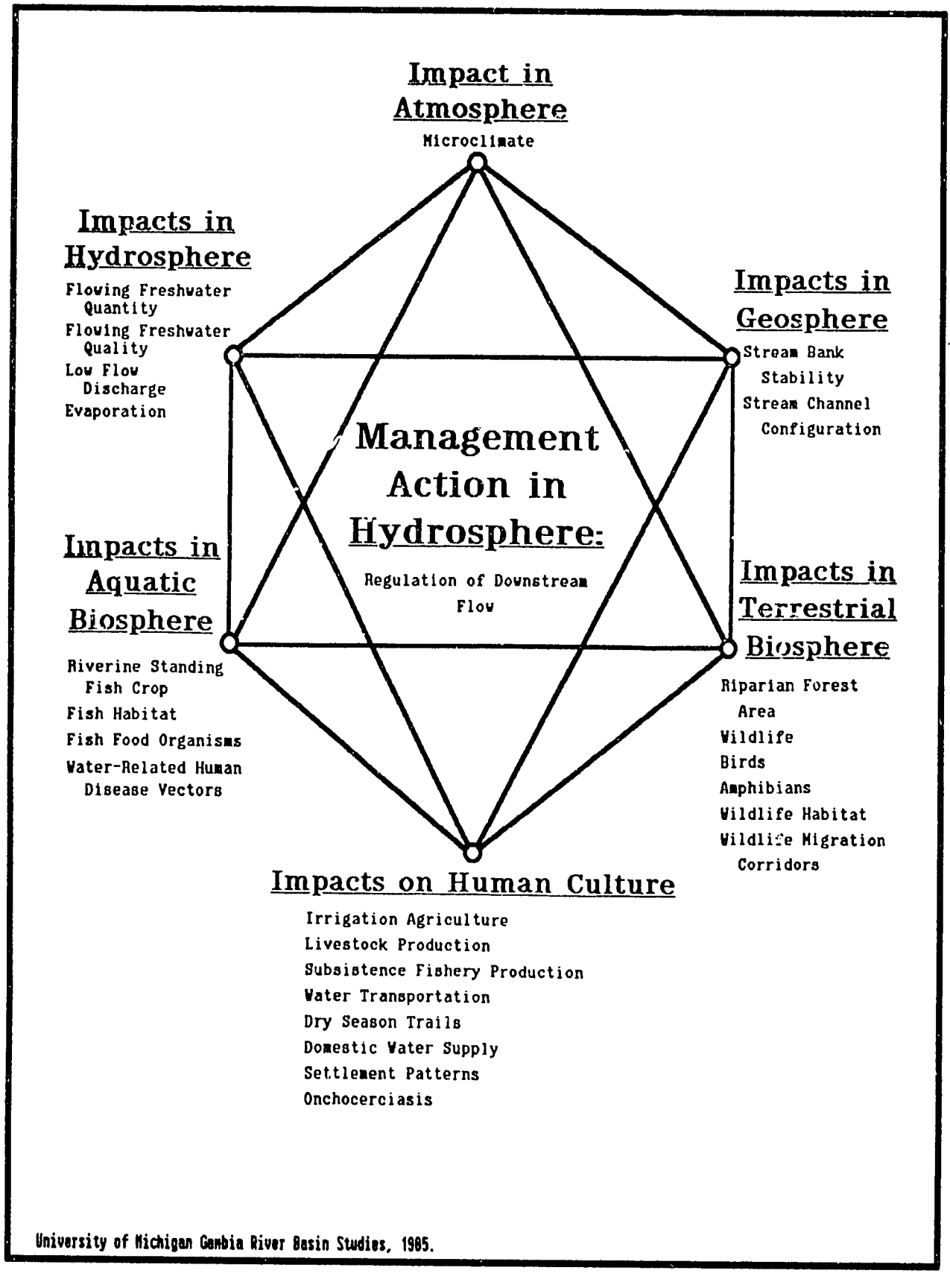


Figure 1.7. A Management Action in One Subsystem Affects Elements in Other Subsystems.

on the Gambia River, will have impacts in all of the subsystems of the basin ecosystem. In the atmosphere, microclimates associated with annual flooding, as well as with lack of flow upstream during the dry season, will be affected. In the hydrosphere, several attributes such as quantity of freshwater flow and low flow discharge will be affected, which in turn will affect stream bank stability and stream channel configuration in the geosphere. In the aquatic biosphere and the terrestrial biosphere, fish and wildlife habitats will be modified, human disease vectors such as the blackfly affected, and vegetation patterns changed. Regulation of downstream flow, furthermore, will have impacts in all of the human subsystems. Socioeconomic production systems such as agriculture and livestock will be affected; socioeconomic infrastructures such as water transportation, and sociocultural institutions such as settlements will be affected; and public health will be affected.

As regulation of downstream flow is but one of many management actions planned for development of the Gambia River Basin, numerous attributes in all subsystems of the ecosystem will be impacted by development projects. And because of these ecosystem linkages, whereby many unintended impacts accompany intended impacts, most basinwide water resource development projects have given rise to a host of problems unanticipated in the planning stages. These have been evident in both the socioeconomic system and the environmental systems.

In the socioeconomic system the benefits of water resource development projects often are less than anticipated. Emphasis on hydroelectric power generation has led to failures to take advantage of fishery production and potential foreshore agricultural production. It has also led to the loss of fisheries downstream as well as the loss of agriculturally fertile and productive land. In addition, the economic costs incurred by the resettlement of displaced populations have been underestimated. Their social infrastructure needs have been misunderstood, food support has been inadequate, and basic services have not been satisfactorily provided.

Numerous social costs have been overlooked. While displaced persons are resettled elsewhere, man-made lakes (a general category that includes reservoirs) during and after construction attract a significant inmigration of alien persons who often are not part of the local culture. The displaced persons, simultaneously, have serious difficulties in adjusting to a changed environment and even changed lifestyles, as they are resettled on unfamiliar land and often placed within new or different social structures.

Numerous health problems have been poorly anticipated and costly. All major development projects in Africa, including the Kariba dam in Zimbabwe and Zambia, the Kainji dam in Nigeria, the Volta dam in Ghana, and the Aswan dam in Egypt, have had their own sets of health problems and increases in the incidence of serious water-associated diseases. Certain diseases such as schistosomiasis and malaria have been made more widespread. The inmigration of alien persons introduces new diseases, sometimes of epidemic proportions. Inadequately planned freshwater and human waste disposal systems have increased the incidence of disease. The health problems and the costs of providing health services together have imposed heavy social and economic penalties on water resource development projects.

In the environmental systems, negative impacts have been extremely costly. Valuable natural resources have been lost or destroyed. Soil erosion has been serious, and has led to the loss of agricultural land as well as created sediment, which has reduced water quality and the productivity of fisheries. With some projects, economically important fisheries have been entirely destroyed, due to losses of spawning grounds and changes in food chains. Alterations in aquatic vegetation have made reservoirs unproductive and even created serious problems with hydroelectric generating equipment. Certain animal species have become endangered as their migration paths have been disrupted.

The development of agriculture and manufacturing enabled by water resource development projects can destroy the water resources themselves or sorely limit uses and values. Excessive and unmanaged use of fertilizer and pesticides can pollute the water resources to such an extent that they become unacceptable for animal and human consumption. Manufacturing and mining wastes can pollute the water to such an extent that it cannot support fish nor be used for human consumption. In other words, attempts to exploit this fundamental natural resource -- water -- for socioeconomic purposes can render it of little value to human society.

Thus, on the basis of past problems and experiences with water resource development projects, OMVG, Member State ministers, other planners, and potential donors anticipate numerous problems with development of the Gambia River Basin, especially in environmental areas. The dams will affect the natural physical, chemical, and biological characteristics of the river. The anticipated use of pesticides and fertilizers in irrigation perimeters will affect the aquatic plants and fishes. Mining and mineral processing activities will affect the quality of the

water. The salinity barrage will disrupt the shrimp migratory and nursery grounds, eliminate a significant stretch of the largest mangrove species, and hold back the nutrients from the downstream estuary.

The dams and irrigation projects will have a significant impact on the wildlife and natural vegetation in the basin. Certain animal species may be endangered or threatened. Commercially and economically important wildlife will be placed at added risk. Soil erosion problems will in turn affect the plant and animal populations. The remaining forest resources in the basin will be put under intensified stress. Animal, insect, and plant pest problems may also become intensified.

The water development projects almost certainly will create public health problems. Changes in the transmission of malaria, schistosomiasis, and onchocerciasis will increase the incidence of malaria and schistosomiasis, and at least change the distribution of onchocerciasis. Population shifts and improved communication networks will accentuate the transmission of disease. If large numbers of susceptible persons are involved, epidemics may occur. The increased year-round availability of water in fields surrounding villages and settlements will lengthen the breeding seasons and increase the year around density of disease transmitting organisms.

As far as the human population is concerned, the water resource development projects are designed to improve the quality of life. Nonetheless, certain problems can be anticipated in this system as well. Agricultural patterns and techniques will be altered considerably, which in turn will change the lives and activities of those involved. The demand for labor will change; the division of labor between the sexes will change; the decisions and relationships among cropping and livestock will change. Population settlement and migration patterns will be disrupted, and in the short run the rural exodus to the city may be accelerated. The marketing system will change, as will the technical support systems. The distribution of income will change. In sum, traditional ways of life will be transformed.

That the water development projects will have these environmental and socioeconomic problems and consequent costs, is to be anticipated. The basic problem, however, is that the existing information about the overall ecological system and the atmosphere, hydrosphere, geosphere, aquatic biosphere, terrestrial biosphere, and human subsystems in the basin, for the most part, is sparse and unreliable. Until these Gambia River Basin Studies, not enough has been known

about the basin to be able to plan the water development projects so that these anticipated problems can be minimized and the anticipated benefits maximized. There has been a lack of basic information on the biological characteristics of the Gambia River. There has been no clear understanding of the interrelationships among the different parts of the river's own ecosystem. The lack of information on the vegetation and wildlife of the basin has made any projections about changes in the terrestrial biosphere difficult or unreliable. Very little has been known about the interrelationships among the various plant and animal species in the basin. The same lack of information has existed in socioeconomic areas. Very little solid data have existed on farm management and practices in the basin, with the least on the Guinean area. Thus, projects to shift from rainfed to irrigated agriculture have been very difficult to plan and implement.

Despite the increasing wealth of knowledge about basinwide water resource development and management, therefore, Gambia River Basin development is fraught with unknowns. This is a serious problem to the Member States, OMVG, and donors alike. It is an even more serious problem to the ecosystem of the basin that will be modified.

I.4. Gambia River Basin Studies

Basinwide water resource development problems not withstanding, the richest and least managed natural resource of the Gambia River Basin -- as so importantly recognized by OMVG and the Member States -- is fresh water. No water is stored behind dams to time its release when needed during the dry season. No hydroelectric power is generated; agriculture is predominately and uncertainly rainfed and insufficient to meet nutritional needs; aquaculture is not practiced; industrial development and mining are virtually nonexistent. No surprise, then, that water resource management is central to the development of the Gambia River Basin.

OMVG and the Member States therefore resolved to integrate the management of the available freshwater resources in the basin while preserving its quality to meet diverse needs. Because of the complexity of water resource development in the river basin, such management entails decisions and actions despite considerable uncertainty and numerous unknowns. Consequently, The University of Michigan, with assistance from Harza Engineering Company, analyzed the basin ecosystem and

its subsystems. This analysis investigated the impacts of water-associated development projects; explored possible tradeoffs between environmental and socioeconomic objectives in order to evaluate alternative development scenarios; and suggested management measures that could mitigate negative impacts and assure effective exploitation of the water resources in the basin. These Gambia River Basin Studies furthermore were designed to help OMVG in institutionalizing its planning and monitoring activities in order to coordinate and manage the development projects effectively.

The Gambia River Basin Studies (GRBS) have produced five primary reports, numerous working documents, and various other products (Annex A). In addition to this report on Water Resource Management and Gambia River Basin Development, the primary reports are:

- Aquatic Ecology and Gambia River Basin Development
- Terrestrial Ecology and Gambia River Basin Development
- Water-Associated Diseases and Gambia River Basin Development
- Rural Development in the Gambia River Basin

The four subject-area reports are designed to be read separately by various users for different purposes. They are integrated in this synthesis volume, the fifth of the primary reports.

The reports have a range of uses from basic planning and decision making to field level implementation of management and impact mitigation measures in at least four broad areas:

- development policy and decision making
- development project planning
- ongoing monitoring and institutionalization
- implementation and adjustment to impact mitigation measures

OMVG, Member State agencies and field organizations, and donors will use the Gambia River Basin Studies reports to define further the problems of water resource development and management; to analyze baseline information on the current status of the ecosystem and various subsystems in the basin -- especially the socioeconomic status of the basin's populations; and to evaluate the trade-offs that must be made between socioeconomic and environmental objectives.

The numerous trade-offs among socioeconomic and environmental objectives are a special focus of this synthesis report. These are determined on the basis of

analyses of the probable impacts of the proposed development projects, especially the dams at Balingho and Kekreti and their associated irrigation projects, and of the potential mitigative measures. They also are determined on the basis of the proposed dams and associated hydroelectric projects in Guinea. Thus, the synthesis report provides an integrated analysis of management actions, subsequent impacts, and follow up mitigation proposals. In particular, it evaluates alternative development scenarios and provides information for OMVG and associated agencies to consider for redirection or modification of proposed development projects. It identifies the priorities to be considered in implementing the projects and the tradeoffs that are involved. The report interprets the research findings, analyses, and recommendations of these four studies in terms of the Gambia River Basin ecosystem.

The four integral subject-area research reports predict and evaluate the impacts of the dams and irrigation development projects. They define the impacts in both environmental and economic terms. They discuss both beneficial and negative impacts and, where plausible, propose management and mitigation measures. To do this each report presents the relevant baseline information on the present status and dynamics of the Basin ecosystem and subsystems. This information also provides the foundation for subsequent studies and ongoing monitoring.

Aquatic Ecology and Gambia River Basin Development projects the impacts of the dams and irrigation projects on the riverine and estuarine ecologies and recommends mitigating measures in response to adverse impacts. The report defines the ecologies in terms of physical, chemical, and biological data and of the interrelationships among them. In addition, the report discusses the fisheries in the basin, marine and freshwater, including the potential of the man-made lake fisheries. It also addresses the impacts of the potential irrigation projects, especially of the uses of pesticides and fertilizer, as well as of the proposed mining projects in Guinea. Cost-effective analyses indicate the economic attractiveness of various projects and mitigative measures.

Terrestrial Ecology and Gambia River Basin Development describes and analyzes the current status of the wild plants and animals in the basin. The report defines the habitats of the animal species and the interrelationships among the species and their habitats. It also defines the relationships between wildlife and agriculture in the basin. For the proposed development projects, it identifies the

probable impacts on the plants and animals and identifies a range of mitigating measures. Wherever feasible, economic implications of the impacts on wildlife and vegetation are introduced. A separate product of this study is a set of 44 land use-vegetation cover maps of the Gambia River Basin.

Water-Associated Diseases and Gambia River Basin Development describes the status of water-associated diseases in the Basin. The report summarizes the existing baseline information and identifies the possible impacts on public health of the proposed development activities. It then recommends mitigative measures and monitoring programs, including the organizational requirements for planning and implementing them. Environmental management as a means of mitigating adverse effects, as well as of augmenting beneficial health effects of development plans, is given special emphasis. A description of the existing medical establishments and services in the basin is provided.

In terms of the basic development objectives of OMVG, Rural Development in the Gambia River Basin is the central document of the four primary studies. Gambia River Basin development has both regional and national objectives: achieving nutritional, economic, and, to some extent, energy self-sufficiency for the populations in the basin and of the Member States themselves. In the context of water resource management, this assumes the construction of dams to store fresh water for irrigation development projects as well as for hydroelectric power generation. This report describes the relevant socioeconomic aspects of the existing farming and production systems in the basin in order to explore the tradeoffs among economic and social factors that must be made when future projects are implemented. It presents an impact survey focussing on the short-term and long-term social and economic impacts throughout the basin of the proposed dams and related irrigated agriculture made possible by them.

Essentially, Rural Development in the Gambia River Basin provides a basis for evaluation of the current and proposed production systems and socioeconomic processes throughout the basin. This integrated set of studies analyzes the implications of shifting from rainfed to irrigated agriculture and installing large-scale water impoundment systems and water management schemes. It also analyzes the consequences of the proposed projects on the affected communities. These analyses provide the basis for consideration of economically and socially viable strategies to reduce the adverse consequences and to enhance the benefits of agricultural development in rural areas of the Basin.

Water Resource Management and Gambia River Basin Development does not summarize the four subject-area reports. Instead, it adapts a management impact network technique to integrate the three environmental studies with the socioeconomic study. The result provides OMVG and decision makers with a comprehensive overview of the implications of Gambia River Basin development as currently proposed. The framework for this overview is the total development scenario -- the implementation of the five dams with their associated irrigated agriculture, hydroelectric, mining, and industrialization projects. This approach provides a means by which OMVG and primary decision makers can evaluate alternative development options implicit in the principal features of the total development scenario.

As with all studies of the future, these five reports can only speculate on probable eventualities. In the face of uncertainty, planners and decision makers must assign probabilities to events that we predict might occur when development actions are taken. Our predictions are based on the best available evidence and precedent. Our assumptions are explained so that planners can reevaluate our projections when, as circumstances change and evolve, they conclude that other assumptions might be more plausible.

In the final assessment, it will be up to the Member State decision makers, with advice from OMVG, to make the value judgements required to evaluate the tradeoffs among the impacts of development projects in order to assess development alternatives. The five primary reports of these Gambia River Basin Studies provide a framework for these subsequent analyses. In doing so, they will help OMVG further to establish itself as an effective coordinating agency for the development of the water resources in the basin. Together, they should strengthen the capacities of OMVG and Member State national agencies to generate and synthesize the additional socioeconomic and environmental data needed for planning and development in the Gambia River Basin.

2. DEVELOPMENT ACTIONS AND IMPACT NETWORKS

The primary water management projects for Gambia River Basin development involve the construction of five dams: Balingho, Kekreti, Kouya, Kankakoure, and Kogou Foulbe. These provide the basis for all other water-related development projects as well as for associated electric power and industrial projects. These development actions will be the direct and indirect causes of impacts throughout the basinwide ecosystem and all of its subsystems, as these are interrelated (Figure 2.1.). Within this basinwide context, subsequent actions to manage the land and water resources, improve agriculture, manage fishery and aquatic resources, and guide urban and regional development will be taken.

These impacts therefore can be analyzed in terms of the specific management decisions and actions required for the development projects. A management decision, such as to create a resettlement village, leads to an action or intervention in the ecosystem that creates a network of impacts -- intended and unintended; this constitutes the results of that management decision. Ideally, they would achieve certain development objectives. Effective implementation of an intervention in the status quo of the basin ecosystem requires anticipation of the causal relationships among the impacts as well as appropriate follow-up management actions to ensure that the intended results are achieved.

The primary management networks consist of those actions and impacts directly related to the interventions of the dam, man-made lake, and irrigation scenarios in the environmental and social systems of the regions affected. These interventions, of course, are both those planned to achieve project objectives and those required to support or implement planned interventions. A dam and its reservoir are planned interventions, while a transportation system is an intervention required to implement the dam project.

The intended impacts essentially are designed to achieve socioeconomic objectives such as increasing agricultural productivity and electrification of rural towns. These impacts necessarily are accompanied by environmental impacts, including sociocultural and public health, that as often as not are negative. Overall, the primary management concern is to optimize the positive socioeconomic impacts and to mitigate the negative environmental impacts.

The impacts often will extend beyond the areas which are the foci of management actions. Regions not targeted by development projects will be

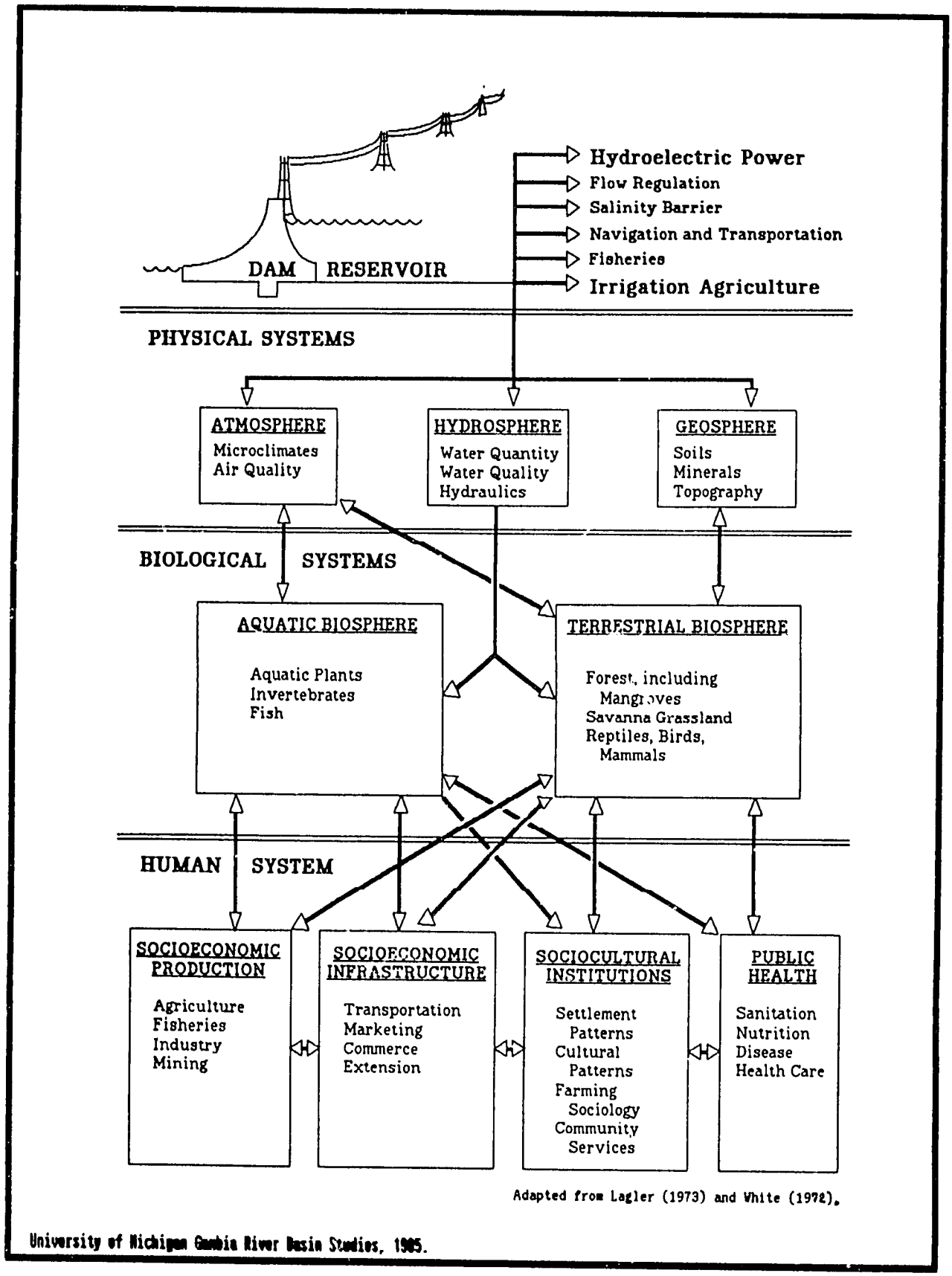


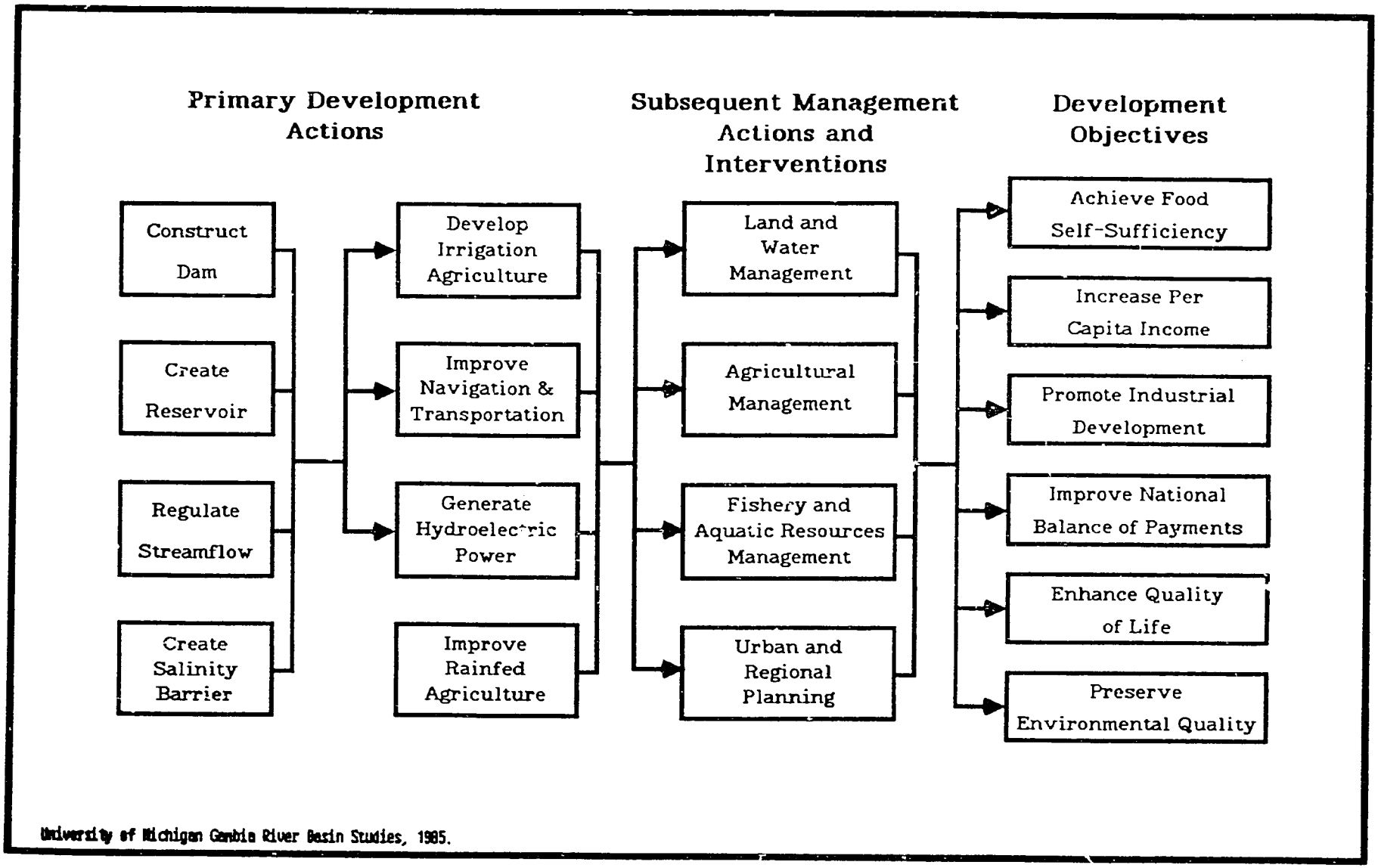
Figure 2.1. Interrelationships of Development Actions and Ecological Subsystems of the Gambia River Basin

impacted, primarily environmentally, although some impacts in these regions also will be economically significant. Given the economic objectives of basinwide development, for example, the impacts in the estuarine system downstream from Balingho Dam to and including the Atlantic in the vicinity of the Gambia River will be both environmentally and economically significant. This will be the situation even though the estuary downstream from Balingho is not the target of any development project except improvement of the already existing river transportation system. Consequently, we analyze the impacts of development actions within a basinwide framework as well as in terms of the specific actions themselves.

2.1. Management Actions and Interventions

The Gambia River Basin ecosystem will be significantly modified by development actions. Long-range plans for total development of the water resources of the Gambia River Basin include the construction of five dams that will change the existing riverine system into a complex river-lake system -- a system, that is, with alternating stretches of flowing and standing water. A total of 1,216 km^2 of lake will be created. The total surface area of these man-made lakes will more than double the water surface area in the basin, which is 1,061 km^2 in the early dry season. Up to 85,000 ha of irrigated agriculture are envisioned; of this, at least 57% will involve clearing and cultivation of land currently uncultivated. That is, considerable additional land will be brought into production.

The actions and interventions in the basin ecosystem can be divided into primary and secondary -- or subsequent -- development and management actions (Figure 2.2.) designed to achieve food self-sufficiency, increase per capita income, promote industrial development, improve national balances of payments, enhance the quality of life, and preserve environmental quality in the basin. The primary objectives of a dam and reservoir are to generate hydroelectric power and to provide water for irrigation agriculture. Some of the hydroelectric power will be used for pump irrigation, but most of the power will be used for secondary development objectives. These include mining and light industry as well as regional development in general. A unique primary objective is the creation of a salinity barrier by the dam at Balingho. Other objectives are to improve navigation and transportation and to improve rainfed agriculture.



University of Michigan Gambia River Basin Studies, 1985.

Figure 2.2. Development and Management Actions for Gambia River Basin Development.

The dam and reservoir, furthermore, create secondary development objectives. Foremost are those for the urban and regional planning required for the construction of villages, the relocation of persons and villages, and the in-migration of numerous outsiders or persons not native to the development region. Marketing and commerce systems as well as additional urban and regional infrastructures will be necessary to support irrigation agriculture and other economic production activities. A fishery and perhaps associated light industry for fish product processing also will be established, along with other light industries which can only be economically viable if adequate infrastructural support is provided. The secondary development actions therefore are dependent on the primary development actions as well as are interdependent among themselves.

The primary and secondary management actions involve specific management decisions that will modify various subsystems of the Gambia River Basin. Each primary management action leads to a series or network of interrelated impacts in various physical, biological, and human systems of the basin ecosystem (Figure 2.3.,. Subsequent management actions and interventions lead to further impacts in these various systems. A fishery management network, for example, is a socioeconomic production network that interrelates actions and impacts from the hydrosphere, aquatic biosphere, socioeconomic production system, and the socioeconomic infrastructure. The impacts of implementation of any one management action, furthermore, are interrelated with those of other management actions. An action such as use of fertilizer to increase agricultural yield can affect the water quality of a reservoir and productivity of its fishery. Carefully planned and effectively anticipated, the network of actions and impacts should result in achievement of some development objectives.

Our analysis focuses on basic clusters of management actions designed to achieve primary development objectives. We identify four management networks: land and water management, agricultural management, fishery and aquatic resource management, and urban and regional planning. These networks are designed in terms of management actions rather than in terms of environmental impact categories in order to integrate socioeconomic actions and impacts with environmental actions and impacts. Each network includes actions and impacts from environmental and human systems so that socioeconomic actions and impacts are related to environmental actions and impacts. Insofar as feasible, therefore, each network introduces economic considerations that can provide the basis for

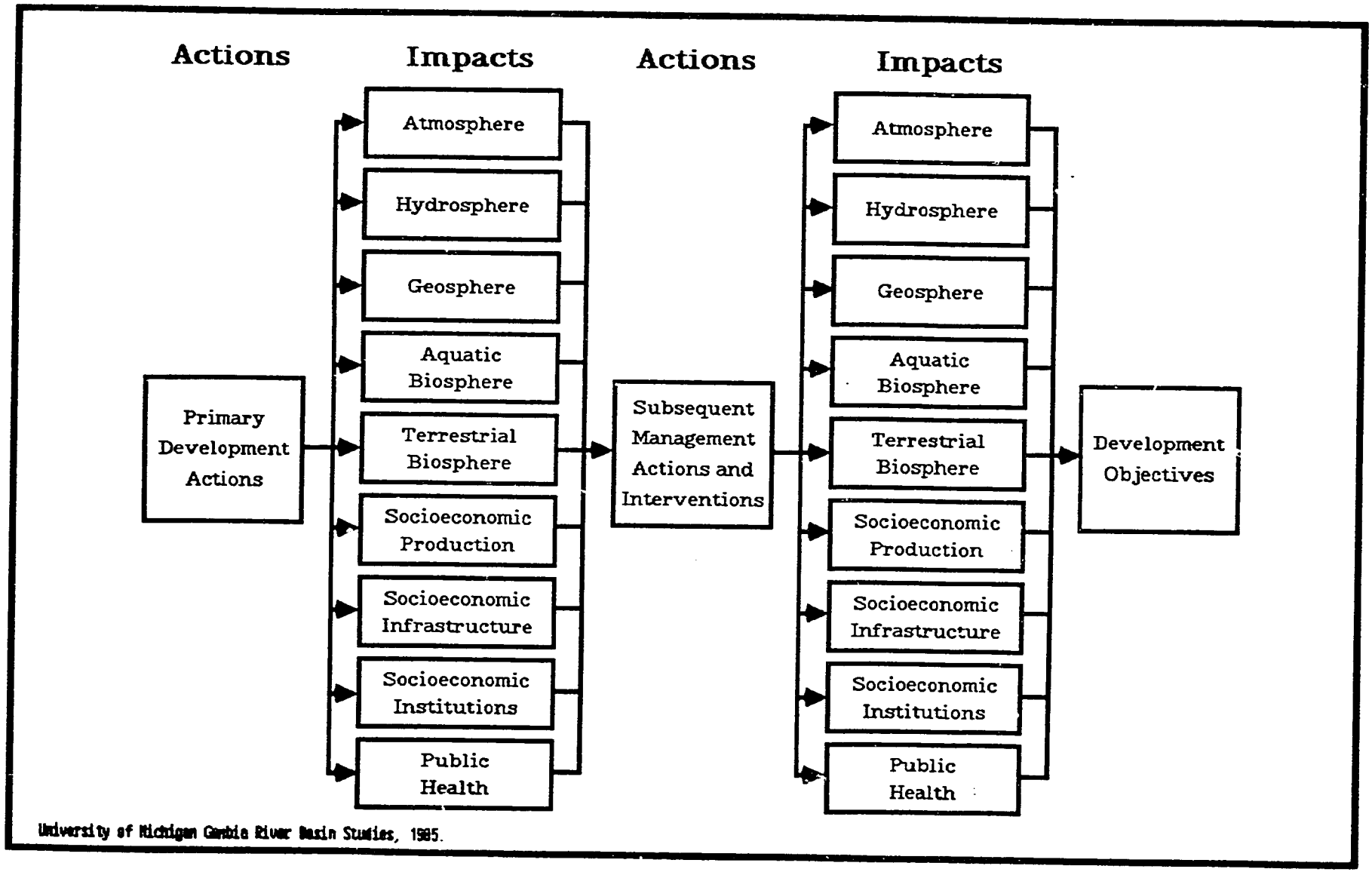


Figure 2.3 Sequence of Actions and Impacts in a Management Network.

subsequent analyses of economic and environmental tradeoffs of development projects. (In this synthesis report we use generalized networks for illustrative purposes. For our analysis we developed detailed networks -- causal rather than environmental energy-transfer networks -- to provide a basis for follow-on social decision analysis or adaptive environmental assessment workshops.)

We have identified management actions relevant to river basin development in terms of the physical, biological, and human systems of the ecosystem (Table 2.1.), drawing upon familiar environmental impact matrices as well as our own studies. The many types of management actions that will affect various aspects of the ecosystem indicate the complexity of river basin development projects. Our analysis, furthermore, as well as other environmental impact analyses, assumes that these actions are interrelated: they cannot be considered in isolation from each other. We classify these management actions and policies in terms of our four management networks (Table 2.2.) in order to analyze the impacts of the various actions. Land and water management includes the actions that will modify the basic land and water regimes of the basinwide ecosystem. The other management actions can be grouped in terms of agricultural management, fishery and aquatic resource management, and urban and regional planning, as discussed in the following chapters. The impacts of various actions are identified and evaluated in terms of these management networks.

2.2. Framework for Impact Analysis

Our primary approach has been to analyze the impacts of development projects throughout the basin rather than project by project. Our basic categories of impacts are those related to the four management networks introduced above. Within those categories, we summarize the significant impacts in terms of the basin as a whole, of a single project, or of a combination of projects. Given the scope of our field studies and the availability of detailed feasibility studies, of necessity we focus on the impacts of the Balingho Dam, Kekreti Dam, and irrigation agriculture projects more than we are able to on the Guinea dam projects.

2.2.1. Hydrology of Proposed Dam and Reservoir Operations

The impacts of the proposed dams must be considered within the framework of the hydrologic implications of the basic operational policies of the proposed dams and reservoirs. For Balingho Dam and Kekreti Dam, these are relatively well

Table 2.1. Management Actions and Interventions

Hydrosphere

Conversion of River to Reservoir
Blockage of River Flow
Creation of Tidal Barrier
Creation of Salinity Barrier
Regulation of Downstream Flow
Flood Control
Control of Reservoir Level
Creation of Canals/Irrigation Network
Alteration of Groundwater Hydrology
Dredging
Water Transportation

Aquatic Biosphere

Conversion of Riverine to Lacustrine Environment
Exotic Fish Introduction
Aquatic Weed Control
Fishing

Socioeconomic Production

Agricultural Land Use Management
Agricultural Management
Irrigation/Rainfed Crop Ratio
Crop Pattern
Labor Allocation
Agricultural Technology
Agricultural Fertilizers
Agricultural Herbicides/Pesticides
Livestock Management
Fishery Management
Fishery Technology
Water Use Management
Dam Construction Management
Dam Operation Management
Forest Management
Plantation Management
Industrial Management
Consumptive Use of Water

Socioeconomic Infrastructure

Marketing Policy
Commerce Policy
Transportation Management
Port Facilities
Labor Policy
Extension Policy

Geosphere

Claiming Land for Settlements
Claiming Land for Agriculture
Modifying Land for Agriculture
Mining
Quarrying/Filling for Dams
Erosion Control
Conversion of Land to Reservoir
Creation of Drawdown Area
Claiming Land for Roads and Trails
Claiming Land for Electric Transmisison Corridors

Terrestrial Biosphere

Clearing of Forest
Burning
Grazing
Gathering
Hunting
Poaching

Sociocultural Institutions

Resettlement Policy
Community Services Policy
Administration Policy
Education Policy
Land Tenure Policy
Construction Support Policy
Migration Policy
Natural Resources Management
Hunting Policy
Tourism Management
Parks Policy
National/Ethnic Heritage Policy

Public Health

Health Services Policy
Medicine
Wells
Education
Chemicals
Treatment Services
Delivery Systems
Training
Sanitation Services
Water Treatment
Environmental Disease Vector Control
Veterinary Services Policy

University of Michigan Gambia River Basin Studies, 1985.

Table 2.2. Primary Management Networks

Land and Water Management

- Water Management
  - Regulation of Downstream Flow
  - Creation of Salinity Barrier
  - Creation of Tidal Barrier
- Land Management Actions
  - Modification of Land Use Classification
  - Hydroelectric Power/ Transmission Systems
  - Mining
- Natural Resources Management
- Construction Management

Agricultural Management

- Land Use Management
- Price Policy
- Credit Policy
- Agricultural Management
  - Irrigated Agriculture
  - Rainfed Agriculture
  - Agriculture Infrastructure
- Livestock Management
- Land Tenure Policy
- Marketing Policy
- Labor Policy
- Agricultural Industry Management

Fishery and Aquatic Resource Management

- Fishery Management
- Fishery Infrastructure
- Water Quality Management
- Fishery Industry Management

Urban and Regional Planning

- Transportation Management
- Resettlement and Migration Policy
- Community Services Policy
- Industrial Management Policy
- Modifications in Sociocultural Patterns
  - Administrative Policy
  - Education Policy
  - Park/Wilderness Policy
  - Archeological and Historic Site Policy
- Public Health Management
  - Health Service Policy
  - Veterinary Service Policy
  - Sanitation Policy

University of Michigan Gambia River Basin Studies, 1985.

defined in the feasibility studies. They are in the formative stages for the Guinea dams. The information is contained in a number of reports by European firms, which include tidal simulations, statistical analyses of streamflows, estimation of reservoir dynamics, and basin simulation models (as outlined in our Aquatic Ecology and Gambia River Basin Development report).

Balingho Dam. The purpose of Balingho Dam is to prevent saltwater intrusion beyond Balingho. This is presumed to allow development of irrigated agriculture on land primarily upstream from Carrol's Wharf, river km 220, past which point the salt frontier has penetrated in recent drought years. Most of the irrigation water, however, will be released from Lake Kekreti, as only a maximum of 5,000 ha of irrigation is considered possible with water from Lake Balingho (RRI, 1984).

The operational policy for Balingho Dam and reservoir is to maintain the reservoir surface levels between +1.3 and +1.7 Gambian Datum (GD), a fluctuation of no more than 0.4 m annually. Despite this narrow range, the surface area of the reservoir will expand from 294 km^2 in the dry season to 716 km^2 in the wet season. Lake Balingho will be extremely shallow, with an average full depth of only 2.1 m.

The water level in Lake Balingho must be maintained at +1.3 GD in order to prevent the formation of acid sulphate soils on land that would be exposed if the water level were to be lower. With evaporation losses, this would happen without a water storage dam upstream. Even then, with irrigation withdrawals, maintaining a minimum level in Lake Balingho is problematic. Thus, Lake Balingho will be unable to supply much water for irrigation.

We therefore have assumed an operational policy for Balingho Dam only in tandem with Kekreti Dam upstream. The gates of Balingho will be closed at least eleven months of the year. Because Lake Kekreti will fill during the wet season, 60 percent of the freshwater that otherwise would spill over Balingho Dam will be contained by Kekreti Dam. Once Lake Kekreti fills, a brief period might occur when freshwater will pass Balingho Dam. For the streamflows on the Gambia River from 1970 to 1983, freshwater would have passed Balingho Dam on an average of 25 days a year. The range would have been from 0 days in 1978 to 70 days in 1974.

In sum, a shallow freshwater lake will be formed behind Lake Balingho. The remaining estuary will receive minimum freshwater flow, and therefore most of the year will be entirely saline -- essentially, it will be an arm of the sea.

Kekreti Dam. The purpose of Kekreti Dam is to produce hydroelectric power and store water for irrigation development downstream. The original concept was

to build Kekreti Dam in tandem with Balingho Dam. Kekreti Dam would provide water year-round for irrigation of up to 70,000 ha as well as maintain the water level in Lake Balingho. Recently, however, simulations have been conducted on the autonomous operation of Kekreti Dam for the additional purpose of controlling salt water intrusion without a dam at Balingho (HHL, 1985).

Lake Kekreti will be entirely different from Lake Balingho. When full the reservoir will store a significant amount of water (3.5×10^9 m^3). However, it will fluctuate from a mean depth of 10.3 m when full to 3.7 m during the dry season. Its surface area will range from 338 km^2 when full to 34 km^2 in the dry season.

Autonomous operation of Kekreti Dam essentially involves a trade-off between water use for irrigation and water release to control penetration of the salt frontier. That is, with 70,000 ha of irrigation, 97 percent of the hydroelectric power generation capacity could be attained if an optional third turbine were to be installed in Kekreti Dam. However, as more and more water is withdrawn for irrigation, the salt frontier will penetrate farther upstream. With no irrigation, the salt frontier will be held just above the Balingho site (at river km 135) by the 104 m^3/sec of flow released for hydroelectric power generation. With 30,000 ha of irrigation, the salt frontier will penetrate to river km 179 (assuming a flow of 45 m^3/sec). With 70,000 ha of irrigation, the salt frontier will penetrate about to its traditional limit (river km 197, 23 km downstream from Carrol's Wharf). (Those hydrologic simulations assume the higher water demand for irrigation in the Kekreti Feasibility Study (AHG/HHL, 1984). The Land Reclamation and Development Consultants (LRDC, 1984) study assumes a lower water demand for irrigation. With the lower demand, maximum penetration of the salt frontier would be to river 175 km.)

The autonomous operation of Kekreti Dam will require compromises and careful management. During the wet season, most of the flow of the Gambia River will be blocked by the dam in order to fill the reservoir. As a result, swamp, tidal, and flood recession agriculture will be affected. At the same time, the pace of irrigation development will be such that for a number of years considerable water will be available for salinity control. Successful autonomous operation of Kekreti Dam, however, depends on the reservoir filling almost to capacity. Simulations show that two times between 1971 and 1980 the reservoir would not have filled and therefore would have failed during the late dry season. Autonomous operation of

the dam will require careful management of water use, especially during years of sparse rainfall.

For our impact analyses, we assume that Lake Kekreti will fill approximately to capacity each year and that 70,000 ha will be developed for irrigation over a 50-year period. However, in accord with the base scenario proposed by OMVG, we furthermore assume the tandem operation of Balingho Dam and Kekreti Dam rather than the autonomous operation of Kekreti Dam. Thus, we assume that the salinity frontier will be held by Balingho Dam the year around and that Lake Balingho will be formed as a freshwater lake.

Tandem Operation of Balingho Dam and Kekreti Dam. The tandem operation of the two dams has been proposed because the autonomous operation of Kekreti Dam will not be able to maintain the salt frontier at Balingho year around once more than 10,000 ha are brought under irrigation. In order to fill Lake Kekreti during the wet season, much of the annual floodwaters will have to be diverted from the downstream flow. The salt frontier will advance during the wet season, whereas currently the floodwaters force it to recede. Consequently, some swamp rice cultivation along the Gambia River will be lost between Balingho and the salt frontier.

The tandem operation of Balingho Dam and Kekreti Dam will preserve this rice production. During the dry season the salt frontier will be contained by the dam. During the wet season the flood waters generated by the watershed and tributaries below Kekreti Dam will, by supplementing the water of Lake Balingho, permit opening of the gates in Balingho Dam for an average of one month a year to allow tides to propogate upstream and enable additional swamp rice to be cultivated.

The tandem operation of the two dams, however, has some hydrologic drawbacks. In order to maintain the water level of Lake Balingho above the minimum +1.3 GD and compensate for evaporation losses, water from Lake Kekreti which otherwise would be available for irrigation will be required. In addition, it is unlikely that the gates in Balingho Dam could be left open for the entire period of swamp rice cultivation without saltwater intrusion and mixing upstream of Balingho. Thus, additional water from Lake Kekreti probably will be required to maintain downstream flow through the gates. This water diversion might prevent the reservoir from filling.

These hydrologic issues remain to be resolved. As a framework for our analysis, we assume that tandem operation of the two dams is possible. The autonomous operation of Kekreti Dam is, in one sense, a mitigative measure. Fundamentally,

however, it is an alternative scenario that should be considered in a decision analysis of Gambia River Basin development. It is only then that the trade-offs can be analyzed in the context of the probabilities and uncertainties involved.

Guinean Dams. Planning for dams in Guinea is in the prefeasibility stage; thus, their operational policies have not been formulated. Kouya Dam is the largest structure proposed for the Gambia River Basin. It will form the largest reservoir in volume, although the surface area of the reservoir in the wet season will be smaller than that of Lake Kekreti (it will fluctuate between 116 km^2 and 80 km^2). The primary purpose of the dam is to generate hydroelectric power, although some 3,000 ha could be brought under irrigation downstream from the dam.

Kankakoure Dam will be on the Liti River 10 km above its confluence with the Gambia River, with Kouya Dam 6 km upstream on the Gambia. The reservoir behind Kankakoure Dam will be rather small in volume and surface area. The sole purpose of Kankakoure Dam is to generate hydroelectric power.

Kouya Dam and Kankakoure Dam will contain all of the wet season flow of the Gambia and Liti rivers. The water would be released on a relatively uniform basis the entire year around. The flows would average 50 m^3/s for Kouya and 16 m^3/s for Kankakoure. The flows likely would occur at twice that rate for twelve hours a day to generate power, and then would cease at night. Some serious concerns have been raised in regard to filling Lake Kouya because its proposed live volume storage exceeds the average annual flow of the Gambia River by 20 percent.

Simulations suggest that the operational policy of Kekreti Dam will be relatively unaffected by construction of Kouya Dam. Perhaps a 4 percent increase in power generation could be achieved at Kekreti with Kouya Dam in place. Regulated discharge from Kouya Dam, however, would enable a reduction in the size of Lake Kekreti by over one third. This reduction would be achieved by regular delivery of water to the Kekreti turbines without the need to store most or all of the annual flood in Lake Kekreti. In order to achieve this reduction, however, Kouya Dam must be deemed hydrologically feasible and built simultaneously with Kekreti Dam.

Because of the uncertainties, we have not assumed the construction of Kouya Dam and its tandem operation with Kekreti Dam. Clearly, the reduction in volume of Lake Kekreti would have considerable implications for the impacts downstream of Kekreti Dam. Primary among these would be that the annual flood would not be diminished as significantly. The reduction in Lake Kekreti also would reduce resettlement requirements and fishery potential.

Kogou Foulbe Dam will be a moderately small structure on the Koulountou River about 150 km above its confluence with the Gambia River (river km 576). The volume and surface area of the reservoir will be modest. The surface area of the reservoir will fluctuate between 38 km^2 and 30 km^2, and it will be about 12 m deep when full. The purposes of the dam are to generate hydroelectric power and to provide water for irrigation of perhaps 12,000 ha around Koundara.

2.2.2. Proposed Irrigation Development

The impacts of basinwide development also must be considered within the framework of the irrigation agriculture projects that will be enabled by water resource management. Currently, the 3,000 ha already developed seem the limit that can be irrigated in the dry season because of the penetration of the salt frontier upstream. When adequate and dependable water supply becomes available, expansion of irrigated agriculture then will depend on the optimal use of scarce but essential resources: agricultural infrastructure, agricultural management, efficient and dependable water supply systems, and availability of labor. The key issue in the expansion of irrigation is how to develop production systems that are technically and economically viable for both farmers and society as a whole.

For The Gambia and Senegal Oriental, feasibility studies of the development of irrigation agriculture between Balingho Dam and Kekreti Dam have progressed to the stage where soils have been classified so that the exact locations of areas with irrigation potential have been identified. Furthermore, an experimental irrigation project has been implemented at Jahaly Pacharr and a specification study completed for an extensive project in the Bansang Nibras area. Although feasibility studies for irrigation in Guinea have not yet been initiated, the areas for irrigation from the Kouya and Kogou Foulbe dams have been identified.

Our discussion of the impacts and implications of irrigation development is based on detailed analysis of the projects proposed for The Gambia and Senegal. This analysis in turn is based on our intensive studies of villages in The Gambia and Senegal (presented in our Rural Development in the Gambia River Basin report). These discussions, while applying directly to proposals for irrigation development in The Gambia and Senegal, should provide a framework for subsequent investigation by OMVG of proposed irrigation development in Guinea.

Basinwide development plans assume that a total of 85,000 ha of land is suitable for irrigation: 53,500 ha in The Gambia, 16,500 in Senegal Oriental, and 15,000 ha in Guinea (AHT, 1984). An alternative proposal for The Gambia is the LRDC proposal

to develop 30,000 ha during 30 to 54 years. Most of the area in The Gambia would be devoted to rice. In Senegal Oriental, where soil characteristics differ, the irrigated crops would include rice, maize, bananas, and vegetables. In Guinea, on the plains of Oudaba downstream from Kogou Foulbe, SENESOL (1982) and FAO (1984) propose 12,000 ha of several crop combinations including vegetables, maize, sorghum, and rice.

Three alternative strategies for incorporating irrigation into existing farming systems are represented by the LRDC Bansang Nibras Pilot Project, the Jahaly Pacharr Project irrigation perimeter and improved swamp rice schemes (Jahaly Pacharr Smallholder Appraisal Report, IFAD, 1982), and the Perimetres Irrigués du Sénégal-Oriental (PISO) scheme (SONED, 1980). Each is based on a set of different assumptions concerning choice of technologies, scale of operation, degree of water control, organization, farmer behavior, labor use, and rates of expansion of irrigated land. From the macroeconomic perspective, these proposals also are based on different estimates of capital investment, operation, and maintenance costs.

Both the Jahaly Pacharr irrigation project and the LRDC Bansang Nibras strategies can be characterized as capital intensive with centralized management, total water control, and double cropping. The LRDC scheme differs from Jahaly Pacharr's in that the farmers are expected to perform most land preparation work themselves rather than rely on project management. The PISO strategy can be characterized as less capital and centralized management intensive with farmer participation in perimeter development. The PISO scheme also has total water control and double cropping. The Jahaly Pacharr improved swamp alternative is characterized by low capital intensity, decentralized management, and only partial water control.

3. LAND AND WATER MANAGEMENT

The characteristics of the land and water systems of the basin provide the basis for an examination of the primary land and water management actions of Gambia River Basin development. Land and water management essentially comprehends the entire Basin system, and the primary development actions will affect most of the land and water resources throughout the basin. In addition, subsequent management actions, such as dam construction and the urban and regional planning for the construction and resettlement villages, will affect these resources. These actions will affect the characteristics or "attributes" of the hydrosphere and geosphere as well as the land use patterns and wildlife in the terrestrial biosphere. These impacts in turn will affect socioeconomic production in the basin. Land and water management will result in important tradeoffs among the objectives of basinwide development.

The primary land and water management actions (Figure 3.1.) are to:

- construct dams
- regulate streamflow
- create reservoirs
- develop irrigation agriculture
- improve transportation systems
- generate hydroelectric power

Construction of the dams will alter the natural hydrologic regime in the basin and enable its management for development purposes. This will regulate the downstream water flow with the dam and create reservoirs to store the water for flow regulation. Regulated streamflow will minimize annual wet season flooding and maintain streamflow during the dry season. A further aspect of flow regulation will be the salinity barrier established by the dam at Balingho, which will prevent saltwater as well as tides from proceeding upstream from there. The reservoirs, especially behind Kekreti, also will serve to provide the water for the irrigation networks supporting the agricultural development objectives.

Construction of dams and creation of reservoirs, furthermore, will enable new transportation systems to be developed and existing ones improved. These are not necessarily implicit in the decisions to create dams and reservoirs. However, an objective of the Balingho project is to provide a bridge across the Gambia for efficient transportation between the north and south of The Gambia, and between

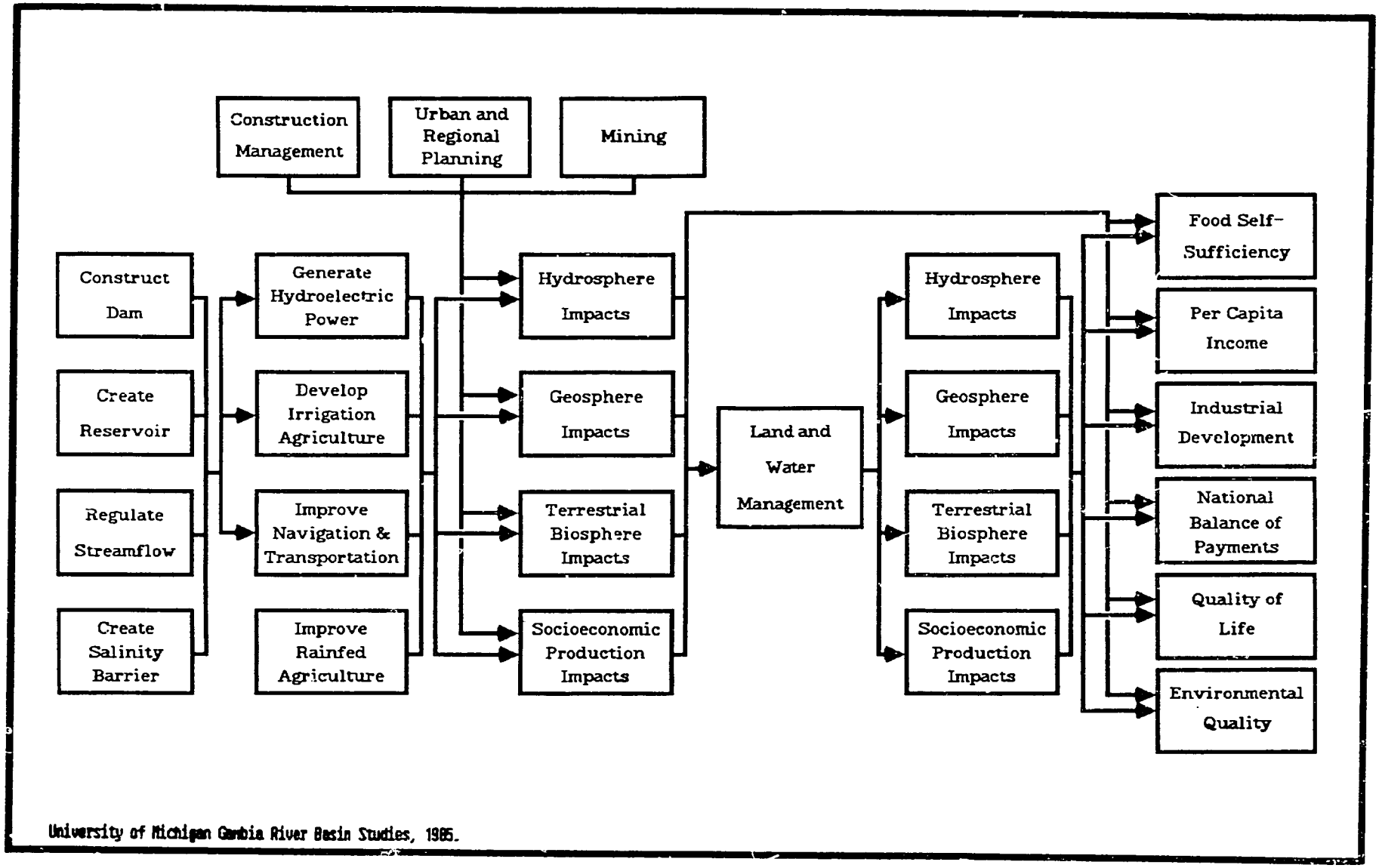


Figure 3.1. Land and Water Management Network.

Casamance and the rest of Senegal. In addition, an integrated river and road transportation system will be required to implement agricultural and other development projects efficiently and to restore communication links that are cut by reservoirs.

A primary objective of the Kekreti project as well as the primary objective of the Guinea dam projects is to produce hydroelectric power. This objective could be pursued by the construction of all of the dams and subsequent creation of reservoirs, except at Balingho, regardless of whether or not irrigation agriculture and transportation projects were to be implemented. Integrated river basin development, however, strives to pursue all of these objectives simultaneously. In addition, it strives to include fishery, urban and regional planning, natural resource, public health, and other objectives as well. Integrated river basin development requires basinwide land and water planning and management.

In the Gambia River Basin, land and water management is designed to increase the amount of agricultural land under irrigation and to exploit the mineral resources known to be present. For the people, these actions will contribute to achieving the objectives of food self-sufficiency and increasing rural per capita income. For the Member States, these should help promote industrial development and improve the national balances of payments. In general, the quality of life in the basin should be enhanced.

At the same time, however, land and water management has the objective of preserving, wherever possible, the environmental quality of the natural systems in the basin and ensuring that human actions do not destroy the vital interrelationships among the various subsystems that form the basin ecosystem. It must do so in the face of the worsening climatic situation of recent years that will be exacerbated by most of the development actions, unless extreme care is taken to manage and mitigate the impacts.

3.1. Land and Water Management Impacts

Land and water management in the Gambia River Basin essentially involves increasing socioeconomic production at the expense of some of the natural environmental quality of the basin. Development actions designed to achieve an increase in agricultural productivity will result in a decrease in environmental quality as well as in natural resource productivity and, indirectly, in some wildlife

populations. This is not only inevitable, but to be expected. Enhancing socioeconomic productivity necessarily involves trade-offs with environmental factors such as the amount of natural vegetation. Although the quality of the tourist experience as well as that of Niokolo-Koba National Park will be somewhat diminished, the tourism potential of the basin could be enhanced (Figure 3.2.). The most important trade-off, however, will be made between the loss of current agricultural production and anticipated future gain in agricultural productivity.

In terms of environmental quality, the development projects will intensify the land degradation process that has been occurring as a result of human activities. That is, in the long run, the significant negative impacts on the environment probably will result from the impacts of the development projects on urban and regional planning and growth in the basin rather than from the impacts of the projects directly on the environment, including wildlife. This generalization must be qualified to the extent that the impacts of the Balingho project on the mangrove ecosystem are considered significant.

3.1.1. Impact Attributes

To identify and describe the impacts of the development projects on the physical and terrestrial biological systems of the basin, we have identified those characteristics of the environment that will be affected (Table 3.1.). The projects will have discernible and measurable impacts on various attributes of the hydrosphere and geosphere. Some of the more important of these in the hydrosphere involve the increase in freshwater surface area, alteration of streamflow and annual discharge of the Gambia River, changes in the tidal actions in the estuary and river, changes in annual flooding, modification of river banks, elimination of the salinity gradient in the river, and reduction of water quality. Important attributes in the geosphere include soil characteristics, such as acid-sulfate soils and salinization of soils, and soil erosion.

In the terrestrial biosphere, important attributes are both environmental and economic. The characteristics of land use and vegetation cover -- forest and natural vegetation areas, agricultural areas, and settlement areas -- provide a primary measure of the impacts of the development projects. Certain attributes relating to the wildlife of the basin also are relevant to concerns for environmental quality. In terms of the objectives of basinwide development, however, the irrigated, rainfed, and swamp agricultural areas are particularly significant.

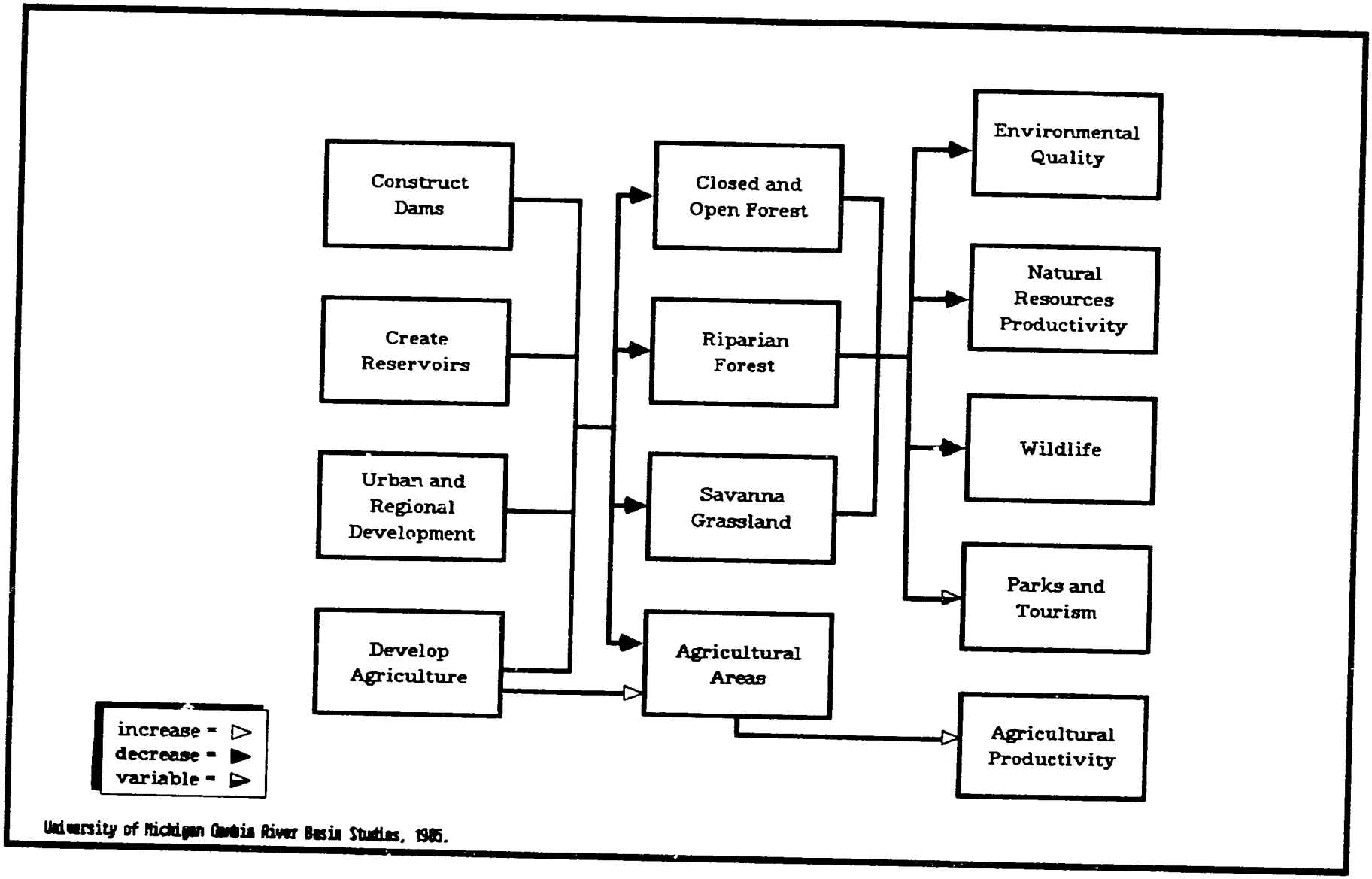


Figure 3.2. Land Use Tradeoffs of Basinwide Development.

Table 3.1. Land and Water Management Impact Attributes

Hydrosphere

Flowing Freshwater Quantity
Standing Freshwater Quantity
Surface Water Area
Evaporation
River Flow Stability
Annual Discharge
Low Flow Discharge
Stream Bed Stability
Stream Channel Configuration
Freshwater Quality
Sediment and Turbidity
Salinity Gradient
Seasonal Flooding
Tidal Flooding
Tidal Mixing
Tidal Flushing
Tidal Amplification
Water Level
Estuarine Water Quality
Groundwater Supply

Socioeconomic Production

Rainfed Agriculture
Swamp Rice Agriculture
Irrigation Agriculture
Forestry Agriculture
Livestock Production
Wood Supply and Products
Plantations and Fruit Orchards
Hydroelectric Power Generation
Mining and Processing
Tourism Income

Geosphere

Topography
Minerals
Soils
Acid Sulfate Soil
Soil Salinization
Soil Erosion
Stream Bank Stability
Seismism

Terrestrial Biosphere

Plantations and Reforestation Area
Closed Forest Area
Open Forest Area
Wooded Savanna and Grassland Area
Riparian Forest Area
Mangrove Forest Area
Human Settlement Area
Irrigated Agriculture Area
Rainfed Agriculture Area
Swamp Agriculture Area
Swamp Area
Barren Flats Area
Rock Outcrops Area
Reservoir Drawdown Area
Birds (Land, Water, Wading)
Large Mammals
Animal Species Composition
Amphibians
Reptiles
Habitat Diversity
Wildlife Habitat
Wildlife Migration Corridors
Rare & Endangered Species
Plant Diseases
Wild Animal Diseases
Pest Species

University of Michigan Gambia River Basin Studies, 1985.

Consideration and further investigation of impacts on these attributes is primary to benefit/cost analyses of development projects, especially of the Balingho project.

3.1.2. The Reservoirs

The most visible and immediate impact of basinwide development will be the creation of five reservoirs (Figures 3.3.-3.6.). Lake Balingho will meander for some 120 km from the dam to Kuntaur, averaging about six kilometers in width. Lake Kekreti will back up along the Gambia, the Tiokoye, and the Diarha Rivers in an arc with a radius of some 45 km -- about halfway from Salemata to Kedougou. In Guinea, Lake Kouya will stretch for perhaps 40 km along the Gambia River, Lake Kankakoure for about 30 km along the Liti River, and Lake Kogou Foulbe for some 100 km along the Koulountou River. The irrigation agriculture potential for which soil feasibility studies have been completed consists of 70,000 ha intermittently along the Gambia River from Kau-ur in The Gambia to Wassadou in Senegal. (An additional 15,000 ha of irrigation is foreseen for Guinea.)

3.1.3. Summary of Impacts in the Hydrosphere and Geosphere

- Water surface area. During the wet season, the reservoirs will double the freshwater surface in the Gambia River Basin. During the dry season the total surface area will decrease by about 30%. This will create a total drawdown area of 726 km^2 for Balingho and Kekreti (the drawdown areas for the Guinean dams will total less than 50 km^2).
- Streamflow. The peak streamflows will be diminished by more than 50%, depending on the year; dry season streamflow will be considerably enhanced as well as maintained in stretches of the Gambia River which currently dry to pools. Streamflow will decrease as water is diverted for irrigation.
- Tidal regimes. The tidal influences will be eliminated above Balingho; tidal amplification will be increased just below the dam. Both impacts, unfortunately, probably will result in a loss of swamp rice production.
- Annual flooding. The floodplains from Balingho to Kuntaur will be flooded by the manmade lake; annual flooding will be considerably reduced above Kuntaur. Both impacts could result in further loss of rice production.
- River banks. Modification of river banks will alter environmental habitats and reduce the exchange of nutrients and material between the land and the river. (The use of fertilizer for irrigation agriculture will replace some of the loss of nutrients.)

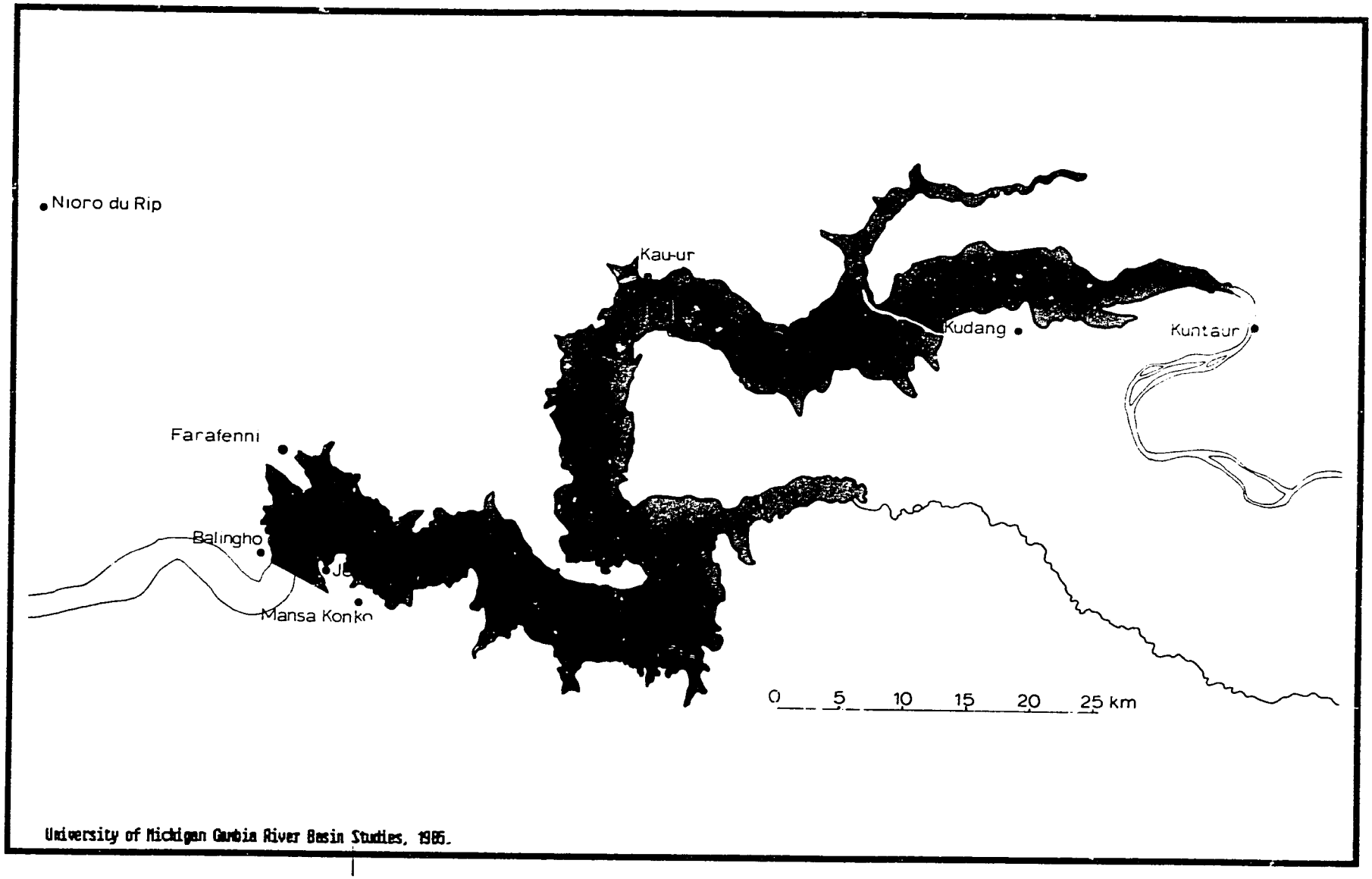


Figure 3.3. Balingho Reservoir Surface Area Representation

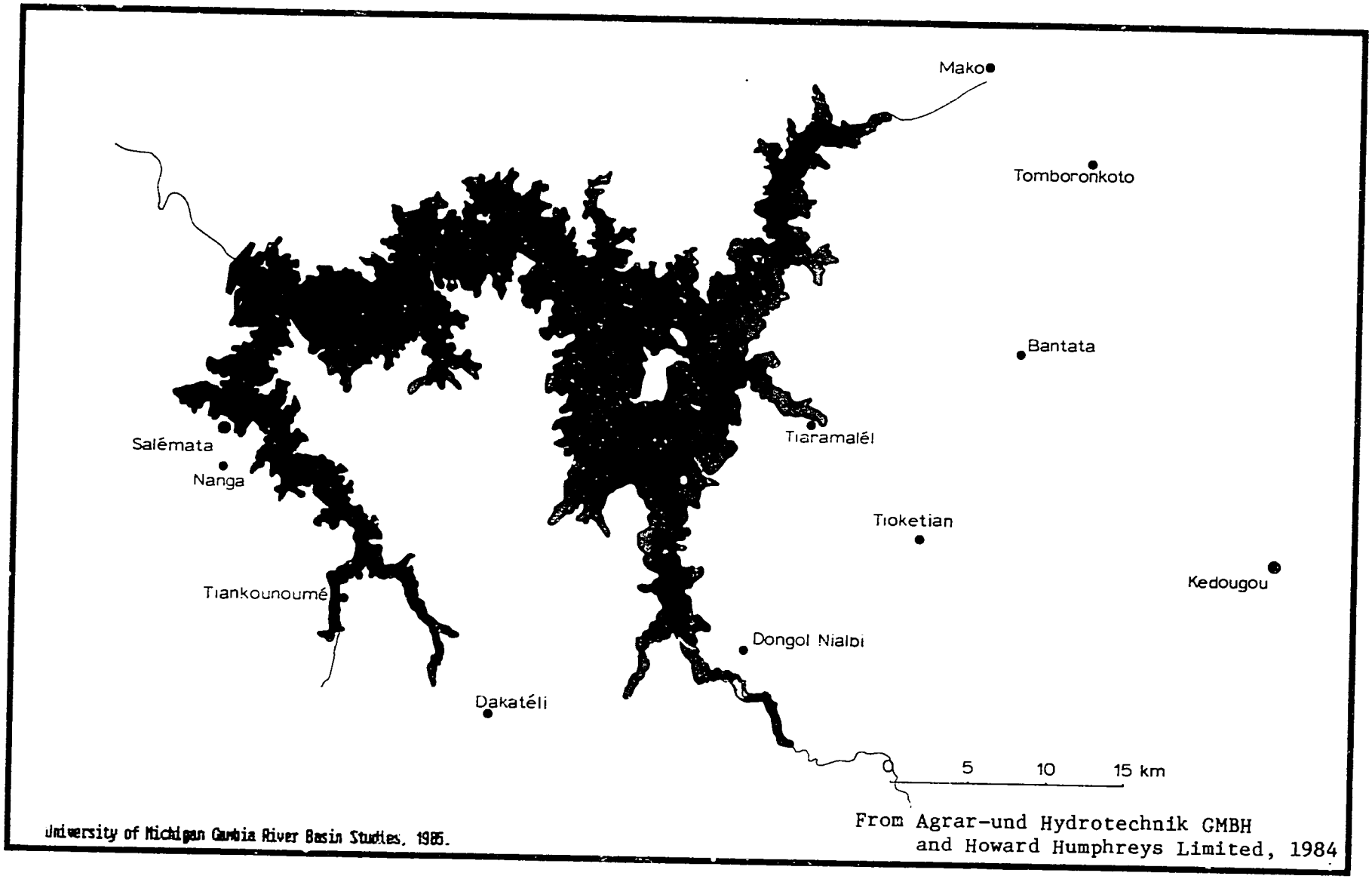


Figure 3.4. Kekreti Reservoir Surface Area Representation

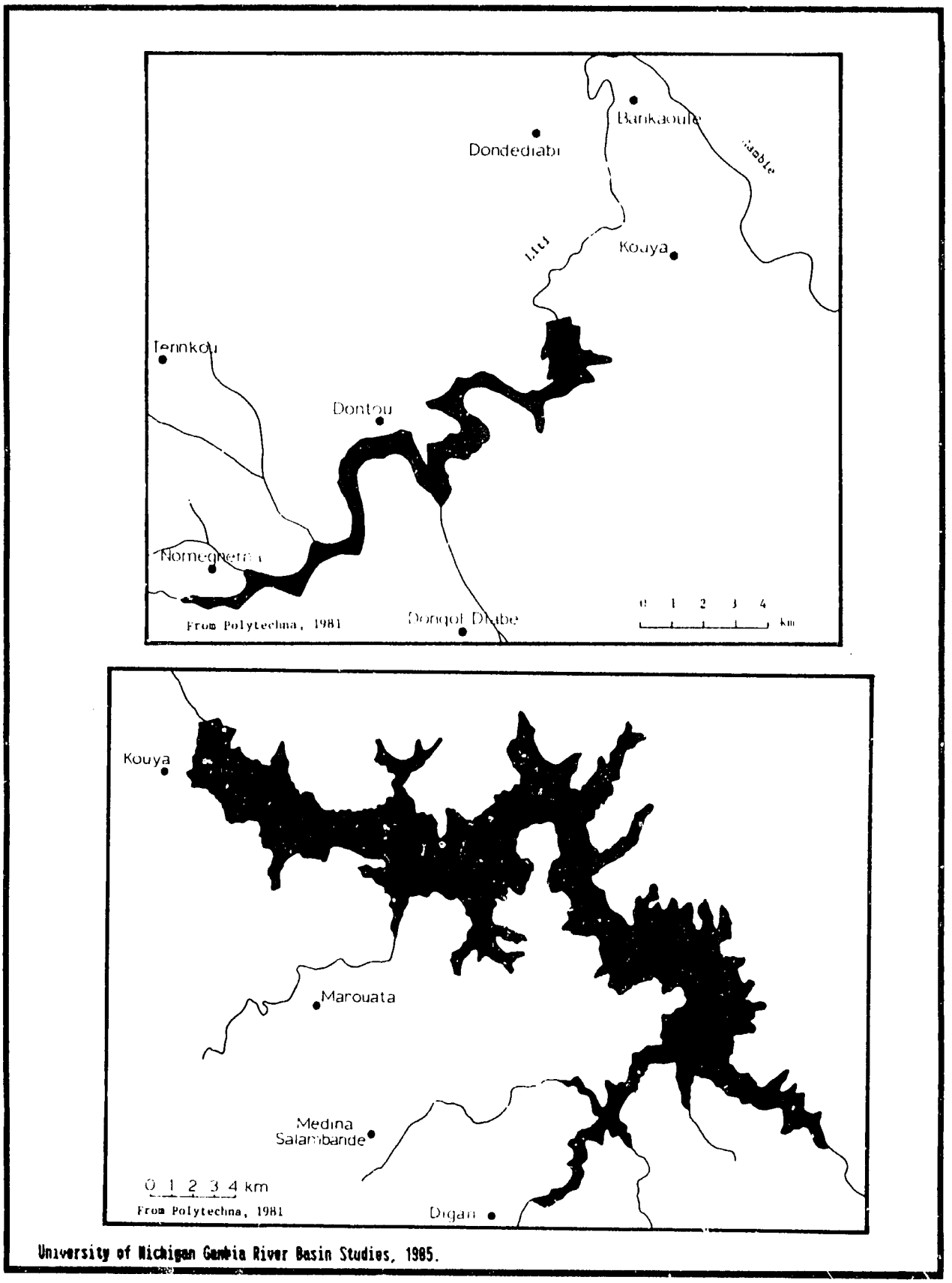


Figure 3.5. Kankakoure Reservoir (Upper) and Kouya Reservoir (Lower) Surface Area Representation

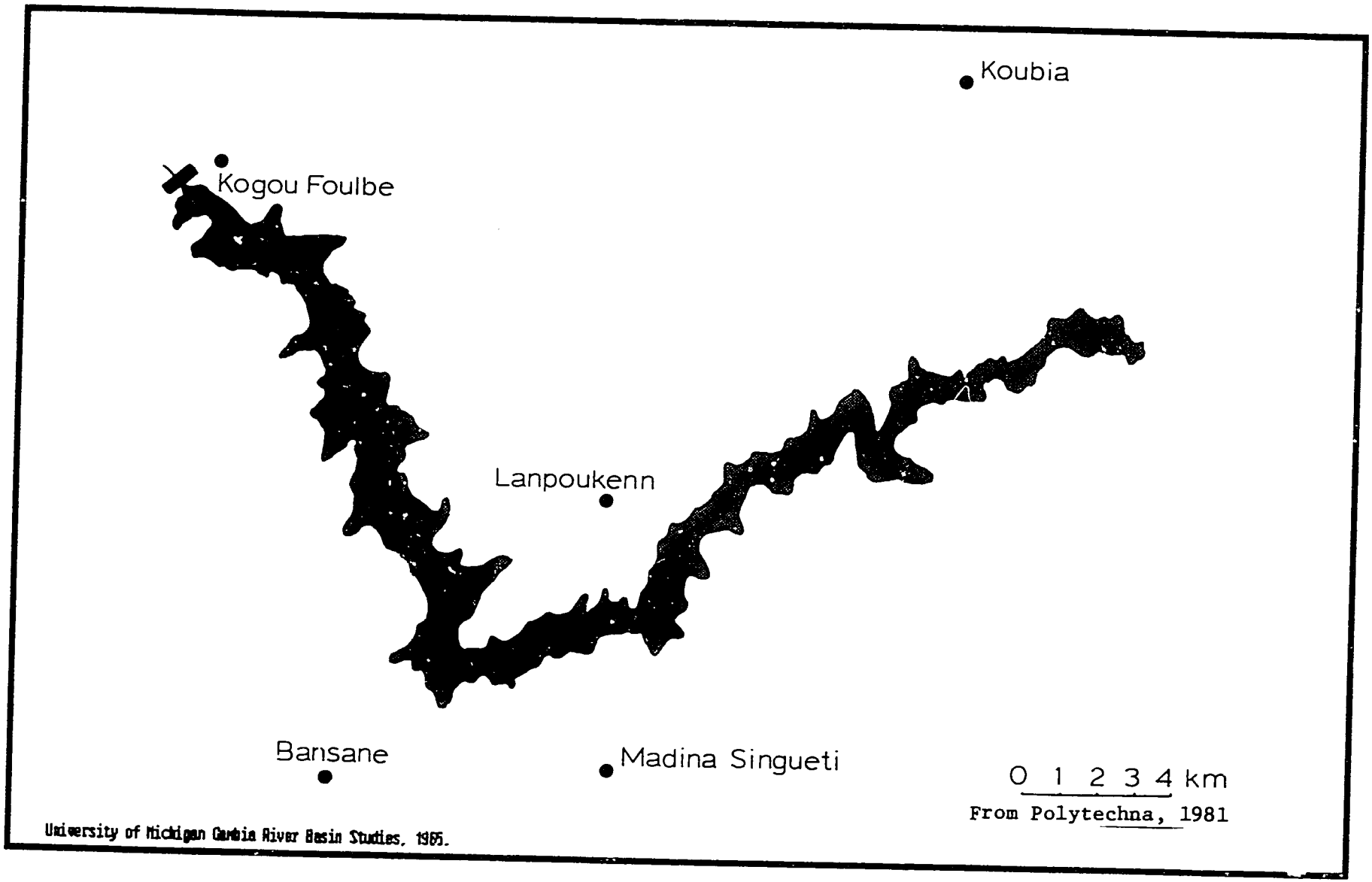


Figure 3.6. Kogou Foulbe Reservoir Surface Area Representation

- Evaporation and evapotranspiration. The combined effect of evaporation and evapotranspiration along with withdrawals for irrigation might cause the water level of Lake Balingho to fall below the design minimum of 1.3m GD.
- Groundwater supply. The reservoirs will increase the quantity of groundwater in the shallow aquifers that supply water for rural populations.
- Salinity gradient. Balingho will eliminate salinity in the water above Balingho. However, it might create a zone of hypersalinity below the dam, thus reversing the salinity gradient from the dam to the ocean.
- Sediment. Sediment will accumulate in the bolons, further reducing the exchanges of nutrients and material between land and water. Because the Gambia River itself has a relatively low sediment load, however, over a 100-year lifespan the reservoirs would lose only from 0.0% to 2.1% of their live storage volumes.
- Water quality. Human activities will tend to reduce water quality.

3.1.4. Summary of Impacts on Land Use and Vegetation

- Land degradation. Development will increase the land degradation process in the Gambia River Basin.
- Current land use and vegetation cover. The existing land use and vegetation cover in the basin in quantitative terms will be minimally affected by development projects -- that is, the percentage of total land in the basin actually affected will be small. The qualitative impacts, however, could be significant.
- Lands flooded by reservoirs. Lake Balingho will flood 49% of the swamp rice land in The Gambia and 12% of the mangrove forest. The loss of mangroves will mean a considerable loss of biological productivity that is both environmentally and economically significant. Lake Kekreti primarily will flood natural vegetation, but less than 0.1% of the area of Niokolo-Koba National Park.
- Land use affected by construction activities. The direct impact of construction will be limited; the impacts on the vegetation and wildlife of the activities of thousands of workers, however, could be significant.
- Land required for resettlement. Up to 400 km^2 of land may be required for resettlement; considerable additional forest land will be required to support the resettled populations.
- Land required for agriculture. Up to 300 km^2 of forest, 320 km^2 of currently cultivated land, and 270 km^2 of swamp will be claimed for agricultural development.

- Land appropriated by urban and regional development. In the long run considerable regional development will be stimulated, which will further change the land use patterns in the basin.

3.1.5. Summary of Impacts on Socioeconomic Production

- Loss of agriculture. Over 19,000 tons of current rice production, 18,000 in The Gambia, will be lost due to flooding of cultivated land by reservoirs and associated impacts.
- Impacts of alternative scenarios on rice production. Irrigation development will take a minimum of eight to ten years to make up the loss of production due to Balingho. With Kekreti only (Balingho delayed until irrigation agriculture is fully developed), annual production after ten years might be 20,000 to 30,000 tons of rice more than with both Kekreti and Balingho.
- Loss of natural resources. Over 1,400,000 m^3 of timber and 3,100,000 m^3 of firewood will be lost due to reservoirs and construction. (Some of this, of course, will be salvaged beforehand.)

3.1.6. Summary of Impacts on Wildlife, Pest Species, and Tourism

- Impacts on wildlife. The direct impacts of development actions on the wildlife in the basin will not be severe, assuming appropriate plans are made and precautionary measures are taken. The year-round supply of water will benefit wildlife. However, the most serious impacts will probably result from human activities.
- Pest species. Development of irrigation agriculture will increase the prevalence of agricultural pests.
- Tourism. Basinwide development will promote tourism by improving transportation, although degradation of the environment will reduce the tourist appeal along some of the Gambia River itself. Should wildlife concentrate around the reservoirs, tourism will be further enhanced.

3.2. Impacts in the Hydrosphere and Geosphere

The multipurpose dams along the Gambia River will have many effects on the hydrology of the basin and, in limited but important areas, on the characteristics of the land in the basin. These will extend from upstream of the Guinea dams to the Atlantic Ocean. They also will involve the groundwater supplies. Water

management for hydroelectric and irrigation purposes, furthermore, will modify many of these primary effects.

3.2.1. Changes in Water Surface Area

The reservoirs created by the dams will about double the amount of surface water in the basin (Figure 3.7.). At present, the Gambia River basin has approximately 1,060 km^2 of water surface, mostly of the Gambia River itself. Almost all of this surface (823 km^2 or 78%) is in The Gambia. The five reservoirs will add a maximum of 1,201 km^2 of water surface to the existing area, with Balingho adding an additional 716 km^2 of water surface in The Gambia alone. As the Senegal portion of the basin now has only 77 km^2 of water surface, the 338 km^2 surface of Lake Kekreti will increase the water surface by more than 400%. Guinea now has 161 km^2 of water surface in the basin, so the water surface area there will be almost doubled.

The significant characteristic of this attribute is that it will vary significantly from the wet to the dry season (Table 3.2.). At the end of the wet season the surface area of Lake Balingho will be 716 km^2 and of Lake Kekreti 338 km^2 for a total of 1,054 km^2; at the end of the dry season the area of Balingho will be 294 km^2 and of Kekreti only 34 km^2, for a total of 328 km^2 -- a reduction of some 726 km^2 of water surface area. (This difference in surface area is called the "drawdown zone," although the term does not apply precisely in the case of Lake Balingho; the water in a reservoir is "drawdown" during the dry season to maintain hydroelectric power production and to irrigate crops.) With Lake Balingho, the drawdown zone will result from evaporation and evapotranspiration and from irrigation water withdrawals upstream, whereas with Lake Kekreti this will result from the release of water for hydroelectric power and irrigation as well as from evaporation. (With effective management, this 726 km^2 of drawdown zone could be considerably productive for crops and livestock, as discussed in Chapter 7.)

The drawdown areas for the Guinea dams, however, will total less than 50 km^2. Kouya will have 36 km^2 of drawdown area, Kogou Foulbe 8 km^2, and Kankakoure -- only 8 km^2 when full -- hardly any.

3.2.2. Changes in Streamflow and Annual Discharge

The dams and reservoirs will cause major changes in the hydrologic regime of the Gambia River. The magnitude will depend on releases downstream, irrigation withdrawals and return flows, and evaporation. The annual discharge of the Gambia

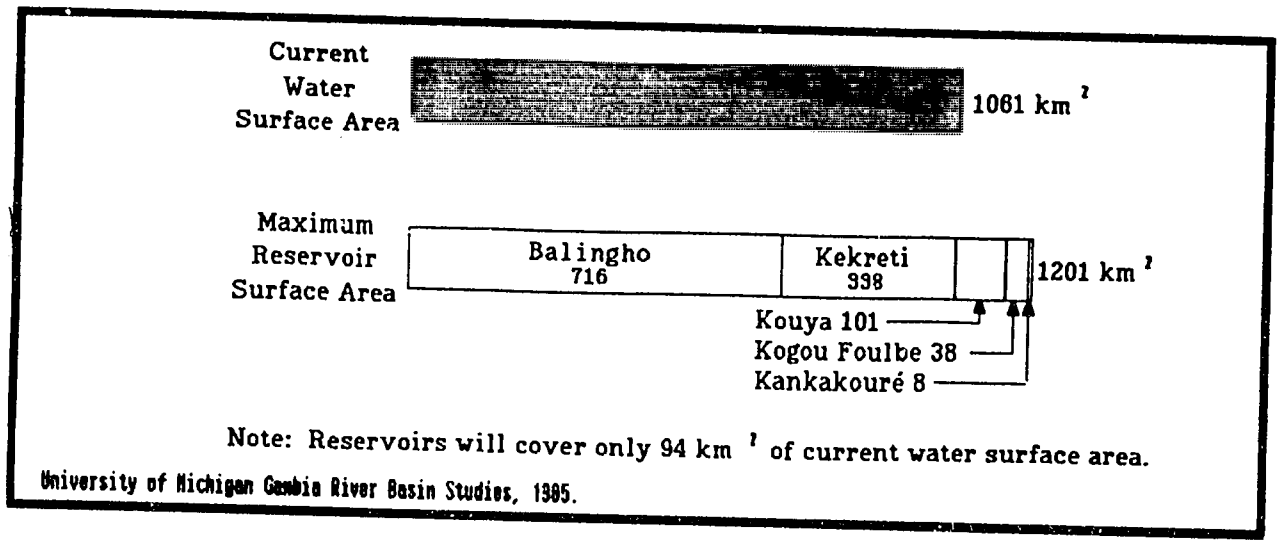


Figure 3.7. Impact of Reservoirs on Water Surface Area in the Gambia River Basin.

Table 3.2. Seasonal Variation in Reservoir Surface Areas and Depths.

	End of Wet Season		End of Dry Season	
	Area	Depth	Area	Depth
Balingho	716 km^2	1.7 m	294 km^2	1.3 m
Kekreti	338 km^2	65.2 m	34 km^2	45.1 m
	1054 km^2		328 km^2	

Variation in Surface Area: 726 km^2.

Note: Variations in surface areas for the three Guinea reservoirs combined will be less than 50 km^2.

University of Michigan Gambia River Basin Studies, 1985.

River at Kekreti will be reduced by the increased consumption of water for irrigation and by augmented evaporation and other losses upstream. The dry season discharge, however, will increase as a result of the managed release of water from Kekreti and the Guinea dams.

The net result of water management will be to reduce the peak streamflows from a range of 300 to 700 m^3/sec to 150 m^3/sec or less. It will considerably increase the low streamflows so that the river will have flowing water in most reaches throughout the dry season. (Currently, above Gouloumbou the Gambia often becomes a series of interconnected pools during the dry season.) The average monthly streamflow of the Gambia at Kedougou ranges from a high of 323 m^3/sec in September to a low of 0.4 m^3/sec in May and at Gouloumbou from 721 m^3/sec to 3 m^3/sec. In 1983, however, the average streamflows were only about 49% and 36%, respectively, of those of the last decade, which itself was a relatively dry period. Given irrigation requirements, these streamflows will be considerably modified. Downstream of Kekreti, for example, with 30,000 ha irrigated, the average streamflow is projected to range from a high of 150 m^3/sec in April to a low of 90 m^3/sec from June through January. With 70,000 ha irrigated, the range will be from 238 m^3/sec in April to 13 m^3/sec in August. These flows will also depend on how the hydroelectric generators are operated.

3.2.3. Changes in Tidal Regimes in the River

The tidal regimes will be changed significantly by the dam at Balingho. The tidal influence will be eliminated above the dam and intensified below the dam. Currently, the tidal reach of the Gambia extends approximately to Gouloumbou, 397 km upstream from Balingho, where a 10-cm amplitude occurs. From Banjul up to Kau-ur, the Gambia River levels are strongly affected by the tides rather than by annual flood discharges. The average maximum and minimum water levels (approximately 2.35 m and 1.1 m GD) vary little at Kau-ur from the wet to the dry season. The loss of tidal influence will create stagnation in many parts of the river, which will increase sedimentation -- especially in the convoluted mangrove bolons. It also will induce the formation of acid-sulfate soils due to the drying out of those areas of the floodplains currently inundated twice a day by the tides.

Below Balingho, however, the dam will intensify the tidal influence due to reflection of the tidal wave at the dam. Tidal amplification downstream will range from 1.5 of normal at the dam to normal at Kerewan to 0.74 of normal about 50 km from Banjul. This change in tidal amplification will affect the areas currently

flooded by the tides. Flooding will extend further inland where the amplification factor is greater than 1.0 -- or the reach from Kerewan to Balingho. In this zone high tides will be higher than present levels and low tides lower. The additional flooded fringe could range from 0 m at Kerewan to about 300 m at Balingho. Where the amplification factor is lower, the decreased flood fringe could range from 300 m at river km 55 to 0 m toward Banjul. The increase in water level also may affect the downstream mangrove forest.

3.2.4. Changes in Annual Flooding

The flood regimes will be changed by the dam at Kekreti and those in Guinea. Each year a large area of the low-lying banks of the Gambia River are inundated by the fresh waters of the annual flood. These floodplains are an integral part of the river environment, providing fish spawning area and waterfowl feeding grounds; they support flood recession agriculture as well. The regulated streamflow from Kekreti will eliminate seasonal inundation of most of these floodplains. Some will become permanently dry, and some will be used for irrigation agriculture.

These floodplains will be upstream from Kuntaur, where Lake Balingho will end (Lake Balingho will inundate floodplains from Kau-ur to Kuntaur). Upstream from Kau-ur the freshwater discharge of the river during the wet season exceeds the tidal flow from downstream. The river level increases from about one meter at Georgetown to several meters at Basse, and annual floods spill onto the floodplain, located in the MacCarthy Island and Upper River Divisions of The Gambia, historically flooding approximately 46,700 ha.

The impact of water management projects on annual flooding upstream of Balingho depends on construction of Kekreti dam. Without Kekreti -- that is, with Balingho alone -- the annual flooding will be very similar to what it is now. With Kekreti, flood peaks and duration will be reduced significantly. The early wet season floods (July and August) will be completely eliminated. Toward the end of the wet season some flooding normally will occur when excess water is released from Kekreti, although the extent of possible flooding is uncertain. Tributary inflows downstream, from the Nieriko, Koulountou, and Sandougou Rivers, will supplement this release. The loss of floodplain which will result in a loss of flood recession agriculture -- as opposed to the floodplain that will be put under irrigation -- cannot be determined with precision.

3.2.5. Modification of River Banks

Regulation of streamflow, as well as development of irrigation agriculture, will cause widespread and permanent changes to the banks of the Gambia River. Periods of high erosion (wet season) and low erosion (dry season) will be replaced by a constant low level of erosion throughout the year. Much of the bank upstream will not be inundated by the annual flood, while the banks between Kuntaur and Gouloumbou will not be kept moist by the tidal flooding. Irrigation systems -- pumping stations, canals, dikes, ditches, and drainage conduits -- also will alter the river banks. These changes will change the environmental habitats of the river and stream banks, as well as significantly alter their function as a mechanism for the exchange of nutrients and material between the land and water environments.

The effects of modification of the river bank and loss of floodplains will be environmental. Some of the remaining riparian or gallery forest along the river will be jeopardized by erosion. Wildlife and waterfowl will lose preferred habitat. Considerable floodplain vegetation will be lost and considerable biological nutrients lost to the river and lakes, as discussed further in Chapter 5.

3.2.6. The Impact of Evaporation and Evapotranspiration

Evaporation and evapotranspiration losses from the reservoirs, especially with regards to Lake Balingho, could have a significant impact. During the dry season these losses could cause the water level in Balingho Reservoir to drop below the design minimum of 1.3m GD -- perhaps to between 0.9 and 0.3m GD, depending on whether or not water is drawn out for irrigation purposes. Evaporation losses will be supplemented by evapotranspiration losses from the aquatic plants in the reservoirs and from the irrigated crops, although the extent of this loss is undetermined.

According to the RRI feasibility study, the loss of water to evaporation and evapotranspiration could mean that releases of water from Kekreti during the dry season will be insufficient to maintain the level of Balingho Reservoir at 1.3m GD. Evaporation in the reservoirs will have the additional effect of increasing the concentrations of chemicals, such as fertilizers, which are introduced naturally and from irrigation projects.

3.2.7. Impact on Groundwater Supply

Maintaining the level of Lake Balingho will increase the groundwater supplies by raising the water tables of the adjacent shallow aquifers, which fall below the minimum design level of the reservoir (1.3m GD) during the dry season. At Kekreti

the reservoir will raise the groundwater level and reverse the groundwater flow -- away from the reservoir instead of toward the river as now. The Guinea dams will have a similar effect on the groundwater supply.

Although lakeside dwellers will have little need to tap groundwater supplies (although for health reasons it may be desirable for them to do so), the increase in groundwater supply for shallow wells could be an important factor in siting upland resettlement villages and, in general, providing water for human use and for garden and small plot irrigation.

3.2.8. Elimination of the Salinity Gradient

The salinity barrage at Balingho is designed to eliminate the salinity gradient in the Gambia River estuary. As an estuary by definition is where a source of freshwater mixes with saltwater, the Gambia River estuary will be eliminated. The Gambia River from Balingho to the Atlantic essentially will become an arm of the sea, while above Balingho the water will have no saline content for all practical considerations. Downstream from Balingho, salinity levels will increase because of evaporation, and near the dam itself hypersalinity -- salinity in excess of the salinity of the off-shore waters -- may result.

This fundamental change in the Gambia River will have profound impacts on the aquatic biosphere, as discussed further in Chapter 5. Marine species habitat will be expanded, while estuarine species could be eliminated. In addition, the migration path from the ocean to the nutrient-rich spawning and nursery grounds above Balingho will be blocked. As discussed below, the mangroves also will be affected, both by the loss of salinity gradient above Balingho and the change in salinity below Balingho. Hypersalinity also will affect shrimp migration habits and, in general, reduce the aquatic productivity of what is now the lower estuary.

3.2.9. Alteration of Sediment Load and Sedimentation

Regulation of streamflow and diminution of annual flooding will alter the sediment load and hence the sediment distribution in the river system. The sediment loads of the wet season will be decreased and the low sediment loads of the dry season increased. Essentially, this will increase aquatic production because increased light penetration underwater will increase photosynthesis. At the same time, the lack of tidal flushing will increase sediment accumulation in the bolons and, especially, in the mangrove bolons. Currently, the tidal flushing scours the bolons and retards their filling by accumulation of organic and inorganic matter.

Once tidal flushing is eliminated, the bolons will fill with silt and other sediment. The result will be to modify stream channels and banks as well as to reduce the exchange of material between land and water.

Sedimentation should have little effect on the reservoirs themselves, however. The Gambia River carries a relatively low sediment load due to its stony bottom and low streamflows during the dry season (never exceeding 50 mg/L in the freshwater portion of the river). Runoff from the annual flood increases the suspended sediment load to only about 100 mg/L. Over a 100-year period, therefore, AHL/HHT estimates that only about 0.5% of the live storage of Kekreti reservoir would be lost to sediment. According to RRI, Balingho reservoir would fill only to -9m GD after 100 years, which is about 10m below the lowest water levels of its live storage volume. Kouya would lose about 0.2% of its live storage volume, Kankakoure 2.1%, and Kogou Foulbe 0.8% (UM GRBS Working Document No. 53).

High suspended sediment levels in the river during the long construction period -- up to five years for each dam -- is a temporary but serious side effect of dam construction. Immediately downstream most forms of aquatic life and their habitats will be destroyed. This to some extent will be irreversible, given the period of years during which the sediment loads will be elevated. The implications of construction activities on any downstream reservoirs are unclear.

Sediment loads also will result from the other effects of development projects. After the reservoirs are filled, settlements will form along the banks, and the local populations will clear forests for agriculture, fuel, and building materials. Additional land will be cleared for irrigation projects and for resettlement purposes. These various activities, including livestock trampling and grazing, will directly increase the sediment load in the water as well as expose soil to erosion for many years.

3.2.10. The Impact of Human Activities on Water Quality

The impact of these human activities undoubtedly will affect water quality as well. Accompanying any human settlement will be waste, debris, garbage, and assorted industrial chemicals and materials. Navigation and roads will lead to other forms of pollution as well as additional debris. Agricultural activities will contribute various chemicals. The result will be to diminish water quality for human use as well as environmental quality.

The potential impacts from mining activities may be the most serious, at least locally. Extreme acidification of water used for washing tailings and pumped from

mines is the most common impact. Due to the characteristics of the waters of the upper Gambia River Basin, even a small amount of acid would lower the pH to below 4.0, where it would become intolerable to most aquatic life. Once acidified, the water becomes relatively useless as a resource -- unfit for wildlife, fish, irrigation, and drinking. Metal contamination is an additional impact of mining. Acidic water combines with aluminum and iron to form compounds toxic to fish and even to humans.

3.3. Impacts on Land Use and Vegetation Patterns

In addition to impacts on the physical characteristics of the water and land in the Gambia River Basin, the development actions will modify current land use and vegetation patterns in the basin. The immediate impacts will result from the flooding of considerable land by the reservoirs. Subsequent impacts will result from the development of irrigation agriculture, which also will modify the land use and vegetation patterns. Furthermore, additional impacts will result from construction activities themselves and especially from the urban and regional development that will occur as a result of the primary development actions. Expansion of irrigation agriculture, therefore, will come at the expense of some of the current economic production and potential. (Additional potential, however, will be created by the drawdown areas.)

3.3.1. Land Degradation in the Gambia River Basin

In general, development will accelerate the land degradation process that has been occurring in the Gambia River Basin. The basin has experienced a dramatic change in land use and vegetation cover from a forest vegetation to general use agriculture, including livestock production. The change has been most extensive in The Gambia and in portions of Senegal Oriental, although it also has occurred in the more densely populated regions of the Fouta Djalon in Guinea. A vast majority of the remaining forest, furthermore, has been degraded by logging, firewood collection, livestock grazing, land clearing, and repeated burning.

In environmental terms the general trend of deforestation essentially is a land degradation process. That is, changes in land use degrade the land in terms of human socioeconomic values. It results in a change of dominance to brush and tree species that are commercially less desirable but resistant to fire and drought. In addition, it results in less fertile soil for agricultural purposes. When the natural

vegetation cover is removed, the nutrients are leached quickly, impairing the ability of deep-rooted vegetation to restore minerals from the deep soil and parent material. Once the vegetation is removed, soil is exposed to direct solar radiation, high surface temperatures, and drying by warm dry winds. Considerable erosion is invited.

During the dry season, human action plays a decisive role in the degradation process. For agriculture, grazing, and settlement, vegetation -- usually tree-like vegetation -- is cut down and burned to create open areas or to promote growth of vegetation suitable for grazing. Most fires are left unattended to burn themselves out. Many spread accidentally and destroy additional vegetation. In combination with the harmattan winds and erosion of the dry season, the result is the replacement of natural vegetation by a degraded cover that has less capacity to retain water and is more vulnerable to continuing erosion and to damage by solar radiation. Once degraded, the land does not regain its original cover even if left undisturbed for a long time.

A further stage of land degradation occurs with intensive exploitation of the land for agriculture, which results when fallowing practices are abandoned. The traditional Sine-Saloum peanut region, for example -- the southern portion of which is in the Gambia River Basin -- has been shifting toward Senegal Oriental. The soil, of only marginal quality to begin with, has been exhausted of nutrients and has become extremely susceptible to erosion. Increasing population and economic pressures to exploit marginal lands will accompany basin development and thereby intensify the land degradation process unless effective planning measures are implemented.

3.3.2. Current Land Use and Vegetation Cover

To describe the effects of land and water management in the Gambia River Basin, we have classified the current land use and vegetation cover in four categories:

- natural vegetation
- agricultural areas
- urban areas
- other areas such as water bodies and barren flats

Land and water management will enlarge the areas of water bodies, agriculture, and urban settlements, thus diminishing the areas of natural vegetation. In quantitative terms, the impacts on total land use and vegetation patterns throughout the basin

might be considered rather minimal. In The Gambia itself, perhaps 14% of the natural vegetation will be replaced. However, in qualitative terms some impacts will be significant.

The Gambia River Basin has about 77,380 km^2 according to our measurements. (The exact size of the basin cannot be determined because the watershed seems to shift continuously in the region near Ndia and Bakel in Senegal). Almost 78% of the basin is natural vegetation, about 18% is agriculture, a little more than 4% water, swamp, and barren land, and less than 1% urban (Figure 3.8.). Of the natural vegetation, 74% (58,000 km^2) is forest of various classification, while most of the 13600 km^2 under cultivation is devoted to rainfed agriculture (Table 3.3.).

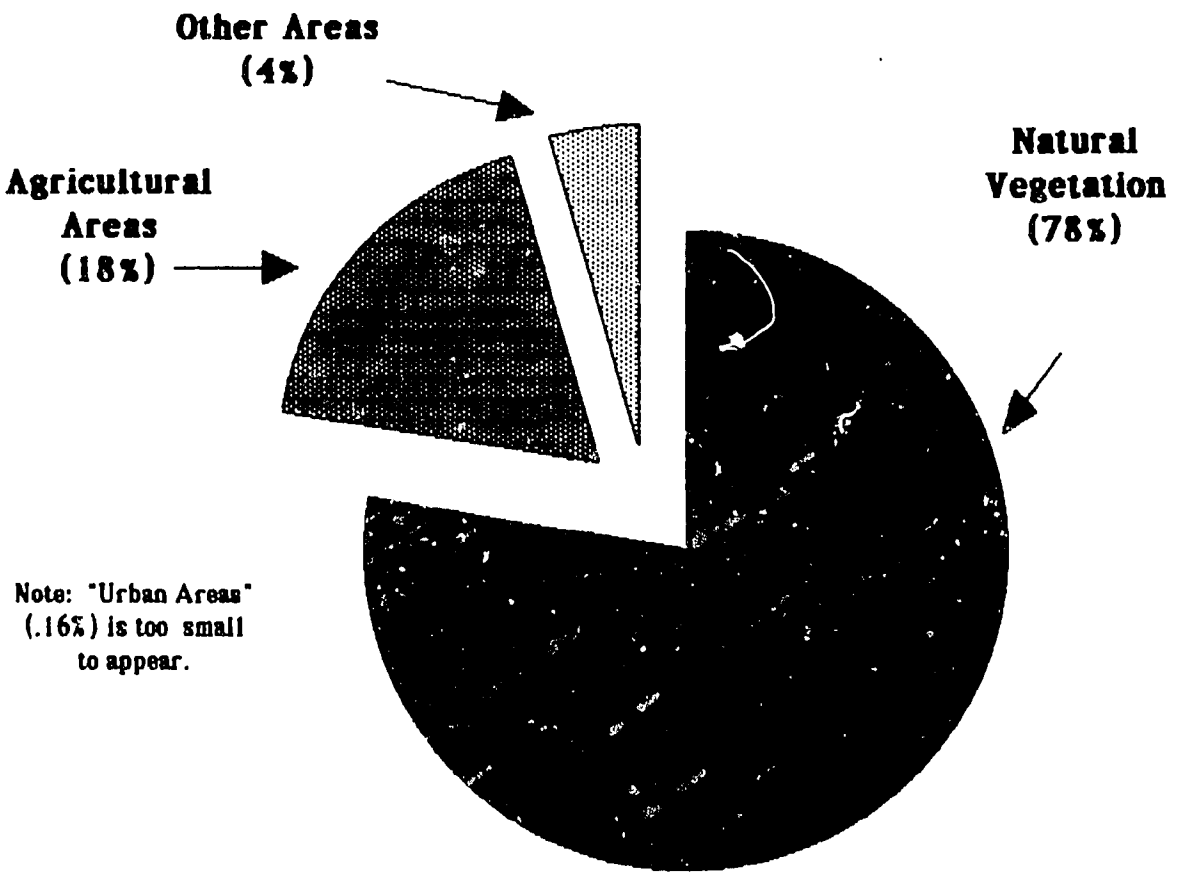
Land use and vegetation cover differs by countries, however (Figure 3.9.). The Gambia has a far larger percentage of its land under cultivation (36.5%) and thus less natural vegetation (44%). Senegal (in the basin) has over 80% natural vegetation and only 17% of the land under cultivation. Guinea is almost entirely natural vegetation (92%).

3.3.3. Lands Flooded By Reservoirs

The five reservoirs will flood 1,216 km^2 of land (Table 3.4.). The land use and vegetation cover to be flooded, however, varies considerably. Balingho primarily will flood three types of cover: mangrove (79 km^2), swamp agriculture (110 km^2), and swamp areas (405 km^2). Kekreti will flood primarily various classes of forest areas (310 km^2). The Guinea reservoirs will flood dense forest (141 km^2). Thus, the overall effect of reservoir flooding will be to reduce the forest areas in the basin as well as swamp areas and swamp agriculture in The Gambia.

The precise inundation area of Balingho reservoir is difficult to predict without contour maps of 0.1 m intervals because the range of water level changes will be by centimeters. Thus, we assume that the "flood" or "alluvial" plain will be inundated, with the man-made lake extending just upstream of Kuntaur (river km 251). In terms of development objectives, the loss of 11,000 ha (110 km^2) of swamp rice will be extremely important. This represents 45% of the total swamp rice in the basin and 49% in The Gambia. The loss of swamp area also will mean the loss of important dry season grazing area.

Twelve percent of the existing mangrove forest along the Gambia River and the bolons will be lost due to the construction of Balingho dam. The mangrove



Gambia River Basin:	77380 sq km
Natural Vegetation:	60336 sq km
Agricultural Areas:	13604 sq km
Urban Areas:	129 sq km
Other Areas:	3311 sq km

University of Michigan Gambia River Basin Studies, 1985.

Figure 3.8 Land Use and Vegetation Cover in The Gambia River Basin.

Table 3.3. Current Land Use and Vegetation Cover in the Gambia River Basin.

		Area (km^2)	Percent
1.	Natural Vegetation		77.98
	Plantations, etc	6.4	0.01
	Closed Forest	13173.0	17.02
	Open Forest	42624.3	55.09
	Riparian Forest	1298.7	1.68
	Grasslands	2610.2	3.37
	Mangrove	623.6	
2.	Agricultural Areas		17.58
	Irrigated	19.3	0.02
	Rainfed	13340.2	17.24
	Swamp	224.3	0.32
3.	Urban Areas		0.16
	Large (>40 ha)	109.3	0.14
	Small (<40 ha)	19.3	0.02
4.	Other Areas		4.28
	Water Bodies	1060.8	1.37
	Swamp Areas	1594.4	2.06
	Barren Flats	90.0	0.12
	Barelands, Rocks	565.8	0.73
	TOTAL	77,379.6	100.00

Definitions:

Closed or dense forest: tree and tree-like areas with a crown closure or cover, as seen from the air, of more than 50%, composed mostly of trees more than 5m mean height.

Open forest and wooded savanna: tree and shrub areas with a cover of less than 50%, which allows sunlight penetration to promote grass and herbaceous vegetation.

Gallery or riparian forest: tree, shrub, and herbaceous vegetation in narrow bands along rivers and streams with year around water; cover can exceed 75%.

University of Michigan Gambia River Basin Studies, 1985.

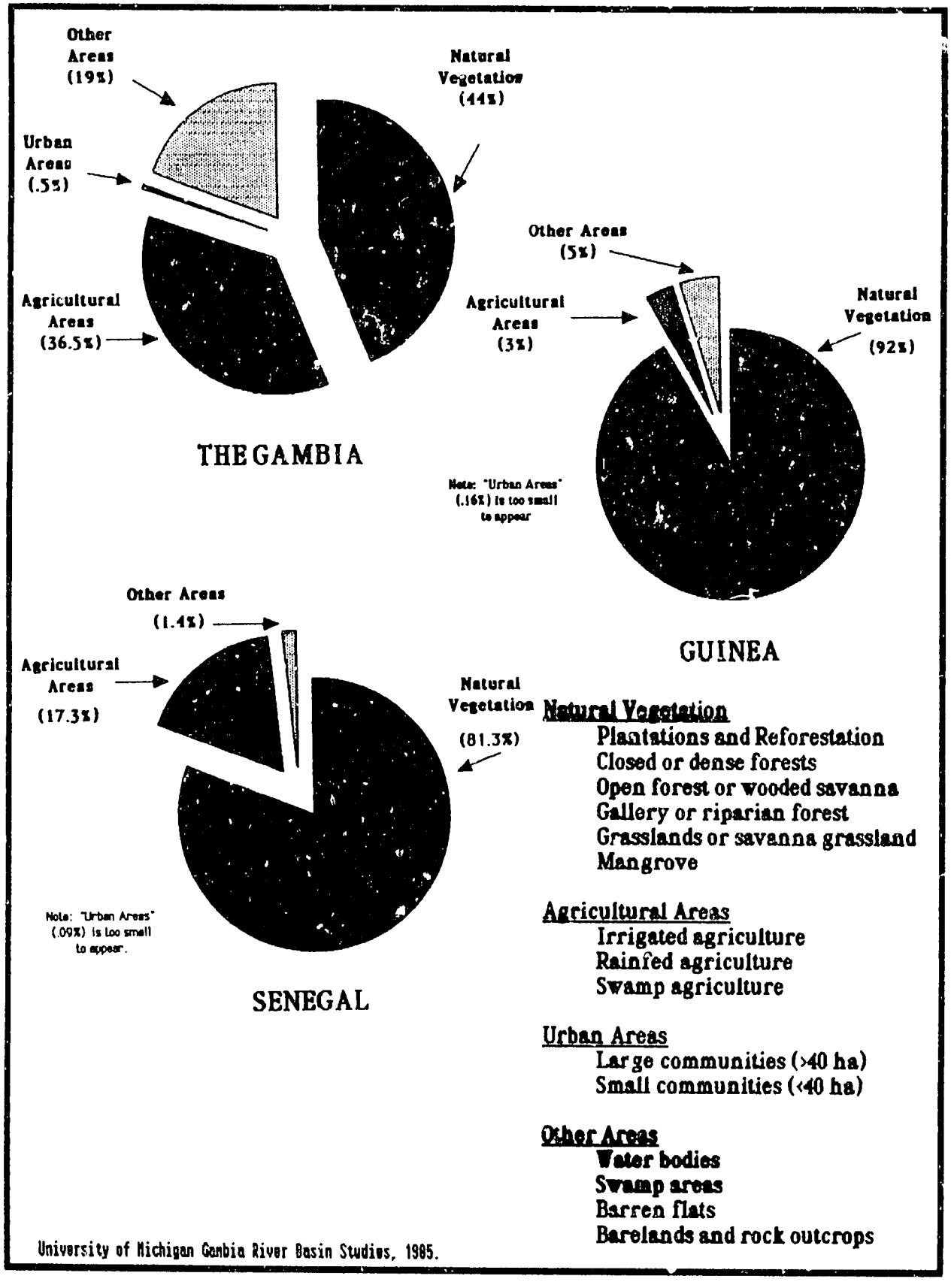


Figure 3.9 Land Use and Vegetation Cover by Countries in The Gambia River Basin.

Table 3.4. Land Use and Vegetation Cover Flooded by Reservoirs.

Class	Area(km^2)			
	Balingho Reservoir	Kekreti Reservoir	Guinea Reservoirs	Total
1. Natural Vegetation				
1.1. Plantation and Reforestation				
1.2. Closed or Dense Forest		91	140.9	231.9
1.3. Open Forest or Wooded Savanna		172	18.8	190.8
1.4. Gallery or Riparian Forest	1.7	47	.7	49.4
1.5. Grasslands or Savanna Grassland		3		3.0
1.6. Mangrove	79.3			79.3
2. Agricultural Areas				
2.1. Irrigated Agriculture				
2.2. Rainfed Agriculture		21	1.4	22.4
2.3. Swamp Agriculture	110.0			110.0
4. Other Areas				
4.1. Water Bodies	94.2			94.2
4.2. Swamp Areas	405.5			405.5
4.3. Barren Flats	25.3			25.3
4.4. Barelands and Rock Outcrops		4	.5	4.5
Total Flooded (km^2)	716	338	162.3	1216.3

NOTE: Urban areas (3.) not included because map scale too small for identification.

University of Michigan Gambia River Basin Studies, 1985.

ecosystems are an integral and fundamental part of the existing estuarine zones of the Gambia River. Their high biological productivity is the source of the rich and diverse fauna of the estuary. Furthermore, they provide the nutrients to the nearshore oceanic environment adjacent to the mouth of the Gambia River.

The primary biological productivity from the mangroves exceeds that of the estuary itself by a factor of 10. This productivity is flushed from the floor of the mangrove forests into small mangrove bolons and the main river channel. Once immersed in the warm water, the mangrove detritus degrades rapidly, enriching estuarine waters with both organic and inorganic nutrients. The tidal action keeps the detritus suspended in the water column while the streamflow causes a slow downstream drift. Numerous organisms feed on this abundant source of nutrients for 175 km downstream to the mouth of the river. They form the base of the food web which supports the important estuarine and coastal fisheries.

The mangrove ecosystems additionally are vital because the rich quiet waters of the bolons and the intricate root systems of the mangroves are ideal spawning and nursery grounds for many fish and shellfish. As a result, many species of fish and shellfish found in and near the Gambia River estuary are estuarine spawners. The impact of the loss of a considerable portion of the mangrove (and of the blocking of migration routes by Balingho Dam, as discussed in Chapter 6) will be both environmentally and economically significant.

An additional impact of Balingho Dam might be the formation of acid-sulfate soils. When the dam eliminates the tidal influence above Balingho, some existing saltwater swamp will dry out. Given the sulphidic nature of the soils in the region, they might become highly acidic. If so, the resulting soil would not support any vegetation, including crops, for many years. Studies of the problem so far are inconclusive, but to the extent acid-sulfate soils are formed the agricultural potential will be diminished. Other studies suggest the possibility that the acidic soils could turn the waters of the reservoir acidic, thereby endangering aquatic life. Our analysis, however, indicates that the volume of the reservoir and the buffering capacity of the water will render this impact improbable.

Lake Kekreti primarily will flood natural vegetation, some of which will be in Niokolo-Koba National Park. Although 77 km^2 of the park will be flooded, this is less than 0.1% of the total park area (9,000 km^2). The flooding of 47 km^2 of riparian forest will be unfortunate because this forest, mostly along the Tiokoye and Diarha rivers, is one of the last vestiges of the original vegetation in the basin.

Kekreti will flood far less agricultural land than Balingho, but the 21 km^2 of rainfed agriculture to be flooded represents some of the most fertile soil in the region of the dam and reservoir. When these alluvial areas are flooded, less desirable rocky land will be left for cultivation. This loss will make resettlement planning more difficult, as discussed further in Chapter 6.

In The Gambia, the loss of swamp agriculture to Lake Balingho will be supplemented by additional losses due to the dams at Balingho and Kekreti. In addition to the swamp and tidal rice cultivation that will be flooded upstream of Balingho, tidal rice will be lost downstream of Balingho between Balingho and Tendaba. At least 600 ha of rice will be lost due to tidal amplification (some estimates are higher). Above Kuntaur, additional dry season tidal rice along the Gambia and some of the tributary bolons will be lost. The extent of this loss, however, cannot be determined without much finer contour maps than are presently available. In addition, along the Sandougou and elsewhere, the attenuation or elimination of wet season floods by Kekreti will lead to the loss of some flood recession rice cultivation. (The extent of this loss cannot be determined until more hydrologic information and small-scale contour maps are available.)

3.3.4. Land Use Affected By Construction Activities

The construction of the dams will have a limited but important impact on the area surrounding the dams themselves. The direct impact of construction activities on land use and vegetation cover patterns can be measured. The indirect impacts of the presence of thousands of workers also will be significant, although these impacts can only be a matter of conjecture based on extrapolation of experiences with other African dams.

The construction activities will cause an additional loss of some 27 km^2 of current land use and vegetation cover in addition to the losses due to subsequent flooding by the reservoirs (Table 3.5.). Most of this will be the loss of about 22 km^2 of closed and open forest, predominately in Senegal and Guinea. About 3 km^2 of agriculture will be lost, 2 km^2 of which will be in The Gambia.

These losses will result from various construction activities, such as the use of land at the construction sites themselves, the building of access and service roads for the transport of materials and equipment to the sites, the excavation of fill for the dams from borrow areas, the clearing of power line transmission corridors, and the establishment of worker villages. These land requirements can be approximated on the basis of the design of the dams and ofprior experiences with dam

Table 3.5. Loss of Land Use and Vegetation Cover Losses Directly Due to Construction Activities (km^2)

	Balingho	Kekreti	Guinea Dams*	Total
Closed Forest		6.00	12.02	18.02
Open Forest	.22	1.23	2.36	3.81
Riparian Forest		.62	.33	.95
Savanna			.02	.02
Mangrove	.15			.15
Rainfed Agriculture	1.70	.83	.17	2.70
Swamp Rice	.30			.30
Rock Outcrops		1.00	1.25	1.25
Total (km^2)	2.37	8.68	16.15	27.20

*Assumes Kogou Foulbe service road from Younkounkoun.

University of Michigan, Gambia River Basin Studies, 1985.

construction. The total land required should be about 27 km^2, which is rather insignificant considering that the reservoirs will flood some 1,200 km^2 of land.

The construction activities will have indirect impacts as well, although these cannot measured. An important impact will be effect of the work forces on the land surrounding the construction sites. The worker villages will have upwards of 2,000 persons, except perhaps at Balingho where the workers may be billeted in surrounding villages (even then the presence of the work force will have an impact). These persons surely will degrade the surrounding forest areas by scavenging for wood and building supplies and by small-scale farming and livestock production, especially at the Guinea sites, where they will need to clear land for subsistence agriculture. They furthermore undoubtedly will hunt and poach illegally, contributing to the impact of human populations on the wildlife of the basin. Finally, they will tend to pollute the natural environment with debris and organic waste. (They also will pose public health problems, as discussed later in Chapter 6.)

A secondary impact will result from the improvement of roads for the heavy construction required for dams. Several hundreds of kilometers of improved roads will be required for construction of the dams, some of which will be new roads and some of which will be improvement of existing roads. Thus, access and movement of people will be facilitated. The constant traffic to and from the construction sites and the temporary movements and influxes of people around those sites will intensify the land degradation activities of the populations living in the regions of the dams.

3.3.5. Land Required for Resettlement

The land required for resettlement of persons displaced by the reservoirs could be considerable. In terms of current land use, the impact of resettlement activities will be significantly larger than the impact of construction activities. The extent of this impact can only be suggested within a wide range because of uncertainties over the amount of resettlement that will be required and the method of implementation that is invoked. Whatever resettlement that occurs will require land for the resettlement village platforms themselves, land for agriculture for those persons, and grazing land for their livestock.

The total land required for resettlement purposes could range from 200 km^2 to 400 km^2 or even more, not including any requirements for resettlement from Balingho. Most of the land for resettlement would come from the clearing of forest land.

The extent of this impact can be illustrated best by the resettlement required by Kekreti, which will require from 170 km^2 to 380 km^2 of land. We estimate that from 8,000 to 18,000 persons will need to be resettled, as discussed in Chapter 6. This number includes both those persons whose homes will be flooded and those persons whose agricultural lands will be flooded. A minimum of 8,000 persons requiring resettlement would require at least 12,000 hectares (120 km^2) of agricultural land (at a minimum estimate of 1.5 ha per person) and an additional 50 km^2 of land for resettlement village platforms. Assuming an animal for every two persons, additional grazing land would be required for 4,000 cattle.

The resettlement requirements for The Gambia and Guinea are less certain. The Balingho reservoir will be in a region far more heavily populated than the region around Kekreti. Given current population growth estimates, over 100,000 persons could live within several kilometers of the floodplain that will be inundated when the reservoir is filled. Numerous persons and even villages, therefore, could lose considerable agricultural land to the reservoir and therefore have to be resettled elsewhere. In our economic analysis, we assume that perhaps 15,000 persons will have to be resettled. Even if some of these persons were to be resettled in irrigation areas to be developed in The Gambia downstream from Kekreti, considerable forest land might be cleared for their village platforms and additional agricultural requirements. In contrast to Balingho, the Guinea dams are in sparsely settled areas. Nonetheless, over 1,000 persons will have to be resettled under much the same circumstances as those from Kekreti, with a requirement of 20 km^2 of forest land at the very minimum.

3.3.6. Land Required for Agriculture

Although the construction of dams and the filling of reservoirs will have the most immediate and visible impact on land use and vegetation cover in the basin, the most extensive long-term impacts may result from the development of irrigation agriculture in the basin. Present development plans anticipate the increase of agricultural production, a significant percentage of which will result from the appropriation of additional land rather than the improvement of production on existing agricultural land.

Development plans for the expansion of irrigation agriculture as presently articulated will require the clearing of about 300 km^2 of forest land: 150 km^2 in Senegal, 100 km^2 in The Gambia, and 50 km^2 in Guinea. Current plans anticipate the development of as much as 85,000 ha of irrigation agriculture (Table

3.6.). Of the land identified by the Land Reclamation and Development Consultants (LRDC) as suitable for irrigation in The Gambia, we estimate 43% is currently cultivated, 36% is swamp, and 20% forest (Table 3.7.). If applied basinwide, this ratio translates into 280 km^2 to 320 km^2 of current agricultural area, 230 km^2 to 270 km^2 of swamp area, and 130 km^2 to 150 km^2 of forest area. Of the land proposed for irrigation with the Guinea reservoirs, almost all is forest. Thus, up to 300 km^2 of forest and up to 270 km^2 of swamp will be claimed for agriculture.

The general process of land degradation that is occurring in the basin will be accelerated by additional impacts of agricultural development activities. When irrigation projects are developed in sparsely populated areas, as will happen in the Upper River Division of The Gambia, Senegal, and Guinea, an in-migration of labor is required to supplement the local labor supply. This means that additional land will be appropriated for human settlement. Furthermore, as the population increases and more land is put under cultivation, additional land will be required for livestock grazing and other activities. "Unclaimed" land appropriated for agriculture, such as wooded savanna and open forest, traditionally has been used for pasture, gathering wood, and hunting by the local population. With current pump irrigation projects, herders have suffered the greatest losses, as livestock needs were neglected in perimeter design. Given the complementary development objectives of increasing livestock production, conflicts between farmers and herders and between crop and pasture can only be resolved by exploitation and further degradation of forest land, although some offset may be achieved by devoting some irrigation agriculture to fodder crops and by use of drawdown areas for grazing.

3.3.7. Land Appropriated by Urban and Regional Development

Accompanying the primary Gambia River Basin development actions will be considerable urbanization and socioeconomic development beyond that initially envisioned. This will commence with the construction activities and sites, expand with the resettlement of persons and the inmigration of persons to development areas, and continue with ongoing development activities. In conjunction with population growth, development projects assume considerable socioeconomic infrastructures such as agricultural extension, storage and markets, transportation, food processing, etc. Even the Fouta Djalon will not escape the pressure. Kouya, Kankakoure, and Kogou Foulbe will intensify colonization of this area, which already has been marked for protection because it is the source of the Senegal and Niger

Table 3.6. Proposed Irrigation Agriculture Development (net ha)

The Gambia	53.500 ha
Senegal	16,500 ha
Guinea	15,000 ha*
Total	85,000 ha

* This estimate is based on preliminary studies and therefore may exceed the net hectarage available.

Note: The Kekreti Reservoir Project Feasibility Study has slightly higher estimates of irrigation agriculture potential as well as a somewhat lower percentage of that potential in The Gambia.

Source: OMVG Draft Indicative Plan.

University of Michigan Gambia River Basin Studies, 1985.

Table 3.7. Current Land Use of Areas Identified for Irrigation Development

Current Agricultural Area*	30,100 ha	43%
Swamp Area	25,200 ha	36%
Forest Area	14,000 ha	20%
Barren Flats	700 ha	1%
Total Area Proposed for Irrigation	70,000 ha	

*Percentage based on LRDC location of the 30,000 most suitable hectares in The Gambia. With total irrigation development of 70,000 hectares in The Gambia and Senegal, this percentage will be lower because of lower population density in the Senegal Oriental regions identified for irrigation agriculture potential. The proportions of current land use of the entire 70,000 ha, therefore, vary from these percentages.

University of Michigan Gambia River Basin Studies, 1985.

rivers as well as of the Gambia River. The cumulative impact of Gambia River Basin development on land use and vegetation cover patterns, therefore, will certainly exceed that which can be quantified in terms of measurable effects of dam and irrigation projects. The process of land degradation, as evaluated in environmental terms, will be accelerated by the subsequent effects of the development projects, both those planned and assumed and those which are inevitable.

3.4. Impacts on Socioeconomic Production

The potential losses of agricultural land and natural resources due to construction of the dams, flooding by the reservoirs, and construction site clearing can be measured to some extent. Up to 19,000 tons of annual rainfed rice production, for example, almost all of which is in The Gambia, seem in jeopardy because of the loss of some 17,000 hectares currently under cultivation, mostly to inundation. This and other evaluations, however, probably must be considered as minimal estimates because additional but unmeasurable losses can be anticipated. The impacts of resettlement and other urban and regional development activities should be weighed in the final analysis, although not all have been considered in our benefit/cost analyses. The loss of rice production eventually would be offset (in ten or more years) as irrigated rice production is expanded with water from Kekreti.

3.4.1. Loss of Agriculture Due to Development

Agricultural losses due to development involve that on some 17,000 hectares (Table 3.8.). (Due to lack of rainfall, the current cultivation and therefore potential loss might be lower than our estimates based on data from prior years.) As discussed above, about 11,000 hectares of swamp rice area will be lost to Balingho reservoir. (Our estimates are taken from analysis of Landsat imagery from 1981 to 1983; the Gambia-German Forest Project estimates of rice production loss are higher, as reported in Rural Development in the Gambia River Basin report.) We furthermore estimate that at least an additional 3,500 hectares of swamp rice upstream from the reservoir will be lost due to the loss of tidal influence and the attenuation of the annual flood, which will reduce the flood recession hectarage. Perhaps 50% of the 4,570 hectares of tidal rice along the Gambia from Kuntaur to Bansang could be lost and at least 25% of the 5,000 hectares of tidal and flood recession rice along the Sandougou. Below Balingho, about 600 of the more than

Table 3.8. Loss of Agriculture Due to Development.

		Balingho Downstream*	Balingho Reservoir	Balingho Upstream**	Kekreti Reservoir***	Kogou Foulbe	Total
Loss of Agriculture (ha)		600	11,000	3500	2200	160	17,460 ha
Loss of Production (tons)****	rice	480	13,200	4200	1600	not estimated	19,180 tons
	maize				1300		1,300 tons

* Assumes about 30% of current production lost due to tidal amplification.

** Assumes from 25% to 50% of current production lost due to loss of tidal influence and to attenuation of flooding.

*** Includes construction site activities.

**** For The Gambia, assumes rice production of .8 tons/ha below Balingho and 1.2 tons/ha above Balingho.

Note: Some groundnut (190 tons) and rice (40 tons) production will be lost to Balingho construction site activities.

University of Michigan Gambia River Basin Studies, 1985.

1,900 hectares of swamp rice will be lost due to tidal amplification by the dam. Kekreti will flood 2,200 hectares of land now under cultivation and Kogou Foulbe 160 hectares.

If these 17,000 hectares presently cultivated are lost to rainfed agriculture, over 19,000 tons of rice will be lost annually. Based on conservative estimates of 0.8 tons/ha of production below Balingho and 1.2 tons/ha above Balingho (Food and Agriculture Organization estimates range from 0.8 to 2.0 tons/ha), 13,200 tons of rice production will be lost to the reservoir; 4,200 upstream from the reservoir; and 480 downstream. The loss to Kekreti will be 1,600 tons of rice and 1,300 tons of maize.

3.4.2. Impacts of Alternative Scenarios on Rice Production

The long-term impacts of development on swamp rice agriculture in The Gambia depend to a considerable extent upon the development scenario that emerges. A Balingho-Kekreti scenario could lead to a considerable loss of rice production for the first eight or ten years. A Kekreti-only scenario could result in an insignificant loss of rice production because key swamp areas would not be flooded. After 10 years, a Kekreti-only scenario might result in a considerable net increase in rice production assuming that penetration of the salt frontier is controlled (as discussed in Chapter 2). These conclusions, however, might be modified when the effect on recession agriculture of controlled flow from Kekreti can be determined.

The base scenario we use throughout this report is the simultaneous construction of Balingho and Kekreti and the development of irrigation agriculture at the slow rate of 30,000 hectares over fifty years, as proposed by LRDC, and a cropping intensity of from 1.2 to 1.8. Given this scenario, it would take a minimum of 8 to 10 years before the production lost due to Balingho would be compensated for by the development of irrigation agriculture (Figure 3.10).

This assumes that Balingho will mean the loss of up to 18,000 tons of rice in the year the reservoir fills and irrigation development commences. This estimate may be conservative. In addition to the 18,000 tons of production lost to flooding, over the first ten years rainfed crop also would be lost due to the development of irrigation agriculture. Given our estimate that up to 43% of the land to be put under irrigation currently is used for swamp agriculture, an additional loss of perhaps 1,000 tons by the tenth year seems possible. (These estimates are based on the average production from 1974 to 1983; currently, production is below average

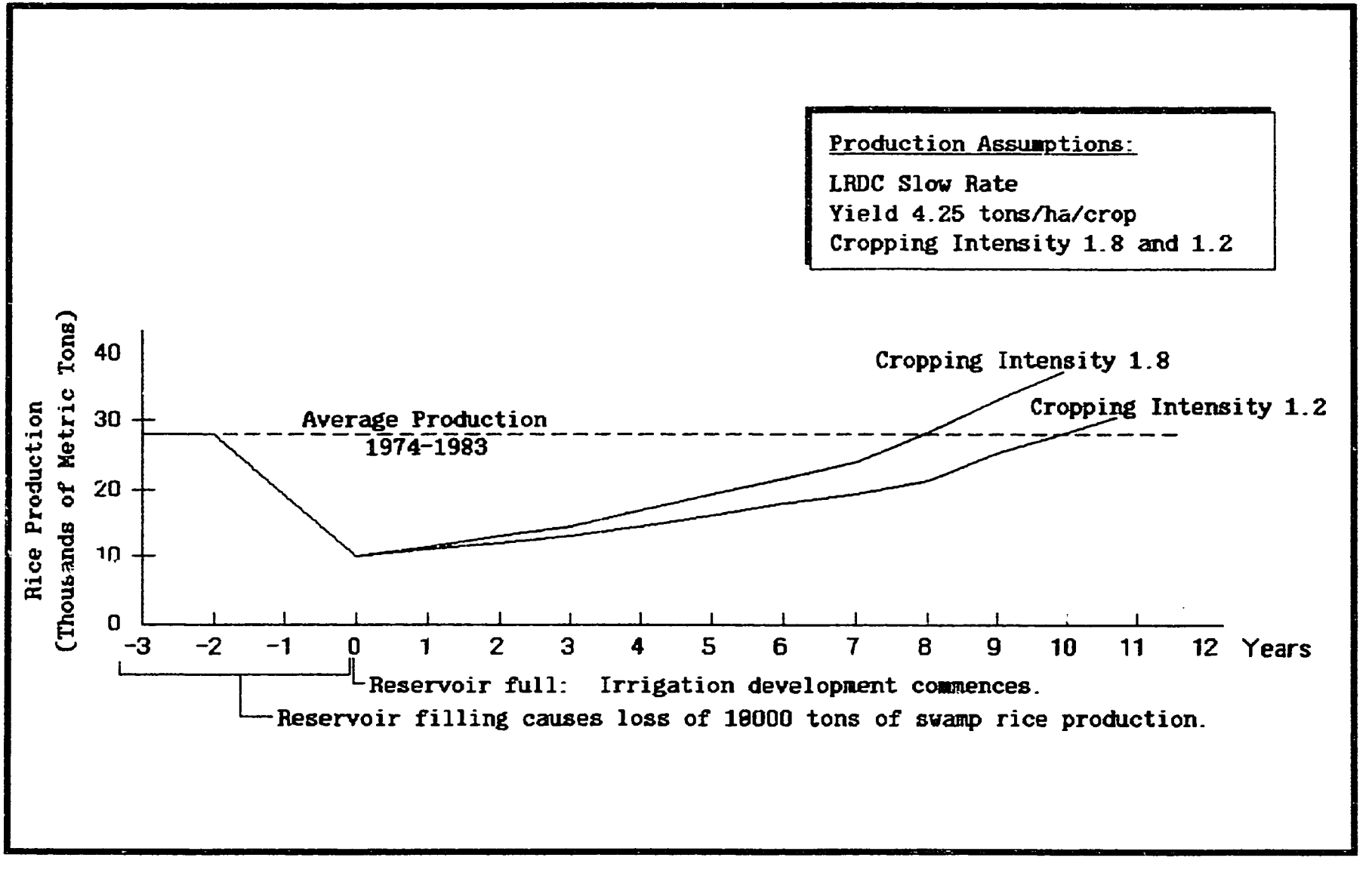


Figure 3.10. Impact of Balingho Reservoir on Gambian Rice Production With Irrigation Development.

because of lack of rainfall. Actual loss at any future time cannot be predicted. Total rice production in The Gambia from 1974 to 1983 ranged from 15,000 to 43,000 tons, according to the Project Planning and Monitoring Unit of the Gambian Ministry of Agriculture, with an average production of 28,000 tons a year for the period.)

Irrigation would be developed at 200 hectares per year for the first three years, then 300 hectares per year for three more years, and then 600 hectares per year until 30,000 hectares have been developed. In the first ten years 3,900 ha would be put under irrigation, with a yield of from 5.1 to 7.65 tons per hectare per year. After ten years, therefore, the yield from these 3,900 ha of irrigation would offset the initial loss of production due to flooding. Subsequent irrigation development, therefore, would result in a net gain in production in The Gambia.

An alternative scenario would be the construction of Kekreti and the development of irrigation agriculture (in The Gambia) at the slow rate proposed by LRDC, with the construction of Balingho delayed for some indefinite time until irrigation agriculture would more than offset the future loss of swamp rice due to Balingho. With this scenario, current swamp rice production would gradually be augmented by irrigated rice production as irrigation agriculture is developed. (In addition, according to the OMVG Draft Indicative Plan, up to 8,000 ha of nonacidic, low saline content land might be reclaimed with controlled flow from Kekreti. This could produce a further increase in production during initial years of irrigation development. However, as more and more water is diverted for irrigation the salt tongue will intrude farther and farther upstream, reaching as far as Kau-ur with full development of irrigation potential.)

The impacts of the two scenarios on rice production in The Gambia are strikingly different. With Balingho (either with or without Kekreti), it would take between eight and ten years to make up the production lost to flooding (that is, to reach the current level of production of swamp rice -- 28,000 tons). With Kekreti alone, an annual net gain in rice production could be realized as soon as the reservoir fills.

Kekreti alone would considerably, if not entirely, avoid the immediate loss in existing rice production that would result with Balingho. (This uncertainty is due to the fact that at this time the impact on recession agriculture of the regularization of streamflow by management of Kekreti Dam remains an empirical question.) With Kekreti, reclamation of nonacidic land, bunding, and partial irrigation, development could begin immediately. Management of the saltwater tongue could also permit

improvements in much existing tidal and recession agriculture. (As more and more water is consumed for irrigation, however, the salt tongue will recede less and less. This means that some existing rice production would be lost. This trade-off requires investigation.) Although these benefits probably will not begin to be realized until after reservoir fill-up, the net effect will be positive. Kekreti could generate important benefits to agriculture even without investments in irrigation -- although these benefits at present cannot be precisely determined.

With Kekreti alone, therefore, any irrigation production that took place would be in addition to existing production except where irrigation expansion occurred on land currently being cultivated. With the slow rate of irrigation expansion proposed by LRDC, in ten years some 3,900 ha of irrigation would be developed. This land, depending upon the cropping intensity, could produce an additional 20,000 to 30,000 tons of rice. With the existing production of 28,000 tons, after ten years or so the Kekreti alone scenario could result in a national production of 48,000 to 58,000 tons. With the Balingho + Kekreti scenario, however, production would reach only 28,000 tons after ten years.

3.4.3. Loss of Natural Resources

In addition to agricultural production that initially will be lost, considerable timber, firewood, and other resources will be lost due to flooding by the reservoirs and clearing of construction sites (Table 3.9.). Presumably some of the firewood will be harvested by the construction workers and local populations. Much of the firewood and timber, however, probably will not be accessible for commercial use. The estimated loss is a one-time loss; if sustained yield from management of the forest were possible, the loss of potential yield over the years would be far greater. Although some of the timber and firewood to be lost could be salvaged, the savings might not be considerable. Sawmills are over 120 km from the mangrove (which has a high timber volume), so transportation costs might be prohibitive. Certainly, the local populations and the workers will salvage some of the wood at all five dam sites, especially that which will be available for several years in the drawdown zones.

3.5. Impacts on Wildlife

Whereas the development actions will have a considerable impact on the vegetation in the basin, they will have less of a direct impact on the wildlife of the

Table 3.9. Losses of Natural Resources Due to Reservoirs and Dam Infrastructure Construction

	Timber (m^3)	Firewood (m^3)	Other Products
Balingho Reservoir	874,000	380,000	Wild fruits, construction material, grazing area, thatch and fencing, wildlife food/habitat
Balingho Construction	1,900	1,700	
Kekreti Reservoir	425,000	2,080,000	Wild fruits, construction material, bamboo, grazing area, wildlife food/habitat
Kekreti Construction	16,000	68,000	Bamboo, grazing area, thatch and fencing
Guinea Reservoirs	84,000	522,000	Wild fruits, construction material, grazing area, wildlife food/habitat
Guinea Construction	9,900	55,000	Wild fruits, construction material, grazing area, bamboo, wildlife food/habitat

University of Michigan Gambia River Basin Studies, 1985.

basin. The loss of vegetation will mean a loss of wildlife habitat and therefore a reduction of some of the wildlife populations. The reservoirs themselves, however, will provide a year around supply of water that will improve the conditions for wildlife. In general, the unavoidable impacts on wildlife of the development projects, such as the construction of dams and inundation of considerable land, for the most part will not be severe. Similar to the degradation of the forest resources by human developments and activities, the most serious impacts on wildlife will be those which result from human activities. The wildlife in the region of a dam will be more at risk from the activities of the 2,000 persons in a workers' village -- and of numerous others drawn to the site -- than from the flooding of the reservoir.

The abundance and diversity of wildlife increases from the mouth of the Gambia River to the Fouta Djalon. This, of course, is related to population density, which in general decreases as one penetrates deeper into the basin, and to the corresponding hunting pressure on the animals except for those protected by Niokolo-Koba National Park. Several large mammals once widespread in the basin have nearly disappeared. The giraffe is gone, the manatee is rarely seen, the elephant is only in the park, the lion and leopard seldom encountered, the eland almost entirely restricted to the park. Even Guinea has lost most of its large mammals. Many of the hippopotami seem to live within the park, but perhaps up to 500 may inhabit various stretches along the Gambia River in all three countries. Along with several of these large animal species, the chimpanzee has become an endangered species in the basin.

The impacts on wildlife will vary according to the habitat that will be affected. With Balingho, the important negative impacts will be on the manatee and the sitatunga. On the assumption that there will be minimal impacts within Niokolo-Koba National Park, Kekreti should not affect wildlife significantly. Few if any animals will be stranded as the reservoir fills, and annual migration movements probably will relatively unaffected. Only a number of eland might be in jeopardy if they remain on the south bank and are no longer under protection from hunting in the park. The Guinea dams should have little effect overall because only a small percentage of total natural forest will be affected.

The Gambia River Basin, especially The Gambia, is well known for its bird life. Over 600 species are known, with 550 having been recorded in The Gambia alone. Bird life is important to tourism in The Gambia, and most of the species important for tourism are tolerant of habitat disturbance. Thus the development

actions should have little more than local effect on bird life throughout the basin except for pest species. The loss of breeding habitat and feeding areas for water-related birds, however, might result in a decrease in visible bird life along the river for tourists, but it might increase around the reservoirs.

Wildlife, especially animals, will be in considerable jeopardy from hunting and poaching, first from the workers and then from the resulting resettlements, new villages, and camps along the shores of the reservoirs. Most hunting by the work forces will be subsistence hunting, although commercial hunting and poaching exists throughout the basin. The manatee will be quite vulnerable to increased hunting pressure because it will be exposed to more human contact than now. Increased fishing also could affect the manatee, which are known to get tangled in gill nets and drown. The hippopotamus will suffer from increased contact with humans. Around Kekreti, the monkey, antelope, waterbuck, kob, and warthog as well as the wild hunting dog could be moderately affected. An additional impact of development activities will be the increased potential for disease exchange between domestic and wild animals.

Past experience suggests a serious increase in hunting pressure, both legal and illegal (poaching) on food and game animals during and after dam construction. First, expatriate construction staff, being short of recreational outlets, characteristically arrive on the site with guns and ammunition and take up hunting. Second, at least in early stages before volunteer local markets and foodshops develop near the construction site, traditional foodstuff inclines to be in short supply for workers and their families. Consequently, they may -- at least for an interim -- "live off the land." Third, after the dam is completed and the reservoir fills, surreptitious hunting increases, especially by persons whose lands were flooded and who have been moved to relocation settlements but have not yet been able to establish subsistence crops.

3.6. Encouragement of Pest Species

The considerable expansion of agriculture envisioned for the basin, however, will encourage the growth of populations of pest species of birds, animals, and insects. A not inconsiderable percentage of increased agricultural production will be lost to agricultural pests.

The hippopotamus will be in further jeopardy because it will become even more of a pest species. Development in general will increase the unwanted occurrence

and abundance of agricultural pests. The expansion of irrigation agriculture along the river, for example, will be extremely attractive to the hippopotamus. Interviews throughout the basin also indicate that the monkey, baboon, and warthog are common crop pests. In addition, rodents are chronic agricultural pests which will thrive with the expansion of agriculture. According to published literature, one irrigated rice seed farm in Senegal was reported to have had an 85% reduction in harvest from rodents. Domestic rodents have been reported to consume up to 65 kg of stored grain per year per dwelling.

Bird and insect pests, as well as plant diseases, will be encouraged by the development of irrigation agriculture, favoring as it does uniformity of landscape habitat and intense monoculture. Birds are a dominant pest species of irrigated rice, and damaged an average of 26% of all of the fields we surveyed. The weaver is an especially ubiquitous species. At present, an annual loss of 1,000 to 2,000 tons of rice due to the weaver seems likely in The Gambia alone.

The net effect of pest species on the development of irrigation agriculture, therefore, will be to diminish the net gain in production. With regard to increased susceptibility of crops to insects and disease, the effect also will be to increase significantly the use of chemicals. This could have a considerable negative effect on the aquatic resources of the basin, as discussed later in Chapter 5.

3.7. Impact on Tourism

At present, tourism in the Gambia River Basin is concentrated along the ocean south of Banjul and in Niokolo-Koba National Park. Tourism in Guinea is virtually nonexistent. In general, basin development might reduce some of the potential for tourism in The Gambia while at the same time increasing the actual amount of tourism throughout the basin. Since direct and indirect consequences of basin development involve the improvement of both road transportation and river navigation, tourism should be enhanced by the increased mobility of tourists. With the development of passable roads, even Guinea could exploit a potential for "bush adventure" tourism. Niokolo-Koba National Park, already popular, could become more so, as accessibility is improved. Excursions up the Gambia River in The Gambia will be facilitated.

Development along the Gambia, however, could reduce its tourist appeal. The loss of the mangroves above Balingho, the loss of riparian forest to irrigation

agriculture, and the loss of riverine waterbird habitat will diminish the quality of the tourist experience. At the same time, the improvement of transportation and facilities along the river seems likely to increase the actual amount of tourist traffic.

As mentioned above, less than 0.1% of Niokolo-Koba National Park will be lost to flooding by the reservoir. Nonetheless, the Kekre+i project will pose some threat to the park and its wildlife because both the dam and reservoir will intrude into the park itself. During construction, illegal hunting and poaching will be a threat. In addition, access roads will threaten some of the wildlife, and borrow pits could degrade the environment in the park near the dam. After completion, development around the reservoir will pose a threat to park wildlife due to increased contacts between humans and wild animals, who also will be attracted to the lakeshore.

Furthermore, hydroelectric power development could harm the park and reduce its attractiveness. The exact location of the electric transmission lines and corridors is unknown. If the connection to the proposed extension of the national grid to Tambacounda were to be routed through Niokolo-Koba National Park, which is one of the alternative routes, the integrity of the park would be seriously compromised.

4. AGRICULTURAL MANAGEMENT

The Member States share the common development objectives of achieving food self-sufficiency, raising per capita income, and improving national balances of payments. According to development strategy, the primary means of pursuing these objectives is to expand irrigation agriculture on a relatively large scale during the next fifty years. This is to be accomplished with water provided by the construction of some combination of dams along the Gambia River. Ideally, this would achieve a stable food supply less subject to the vissicitudes of weather and international market prices. Currently, The Gambia has to import considerable quantities of cereals (60 percent of total consumption). In addition, our field studies indicate that Senegal Oriental and Guinea also are not self-sufficient in cereal production despite common assumptions to the contrary.

In the face of a decline in rainfall and high population growth rates, since 1970 per capita rainfed agricultural production has decreased. This has led to soaring foreign exchange expenditures for imported cereals, a situation that becomes worse when policy measures are consumer-biased. Given the problems inherent in this situation, irrigated agriculture is thought to be more secure and to provide a higher return on investment. With propitious soil and sunlight conditions for rice, double cropping might be feasible in The Gambia and Senegal. Thus, irrigation theoretically provides the possibility of achieving significant increases in food production.

4.1. Management Requirements

The development of irrigation agriculture, as presently conceived in the various development proposals, requires considerable investment in order to establish, maintain, and manage irrigation perimeters. These irrigation schemes require significant technical, structural, administrative, and marketing support (Figure 4.1.). In addition, they depend on allocation of resources at the household level and the willingness of the household to take the risks associated with the proposed irrigation schemes. Achieving agricultural production goals can be highly problematic because of the complex agricultural management network required.

The complexity of agricultural management is illustrated by the numerous attributes that must be taken into account (Table 4.1.). In socioeconomic production

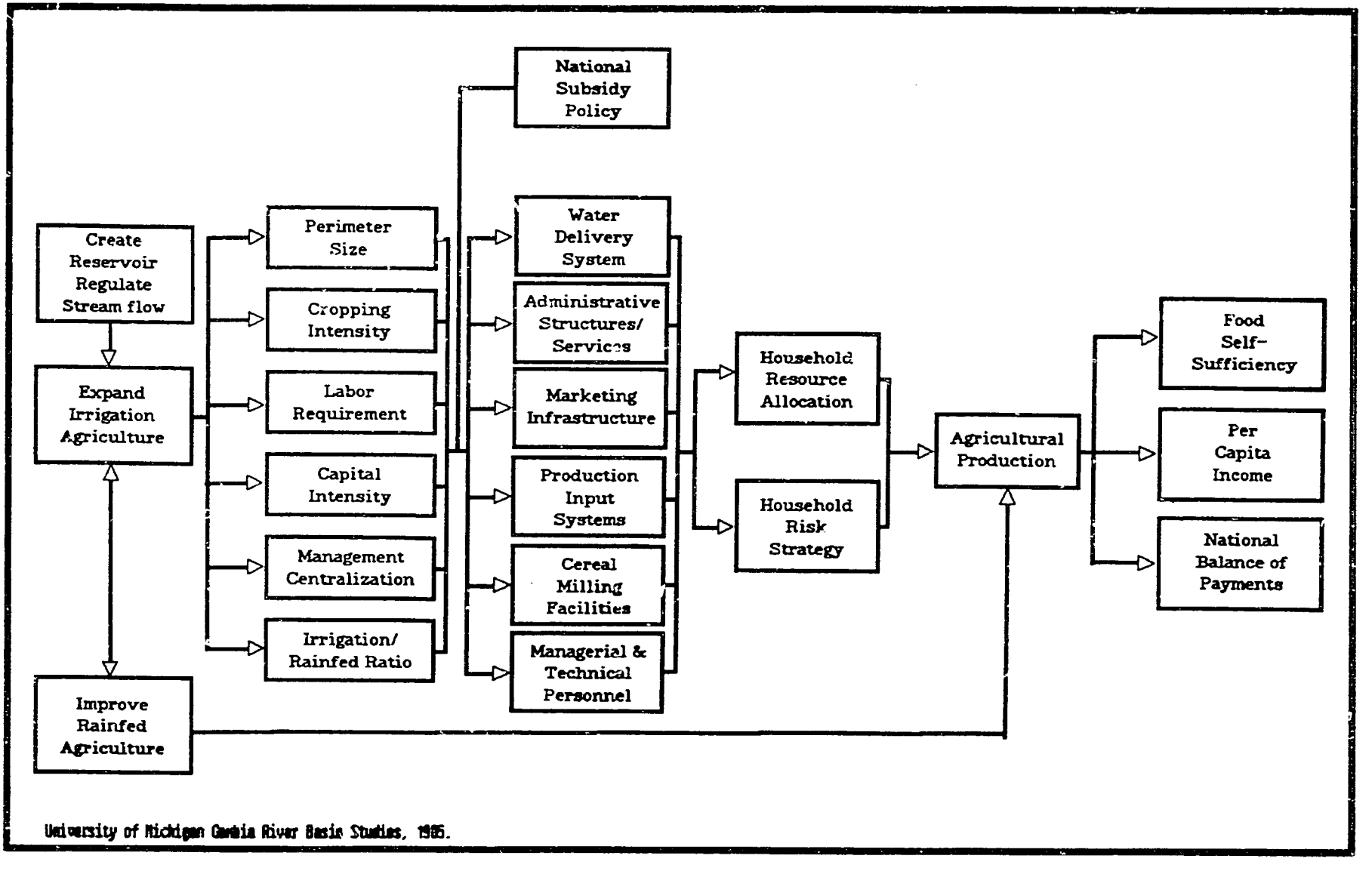


Figure 4.1. Agricultural Management Network

Table 4.1. Agricultural Management Attributes

Socioeconomic Production

Rainfed Agriculture
Swamp Rice Agriculture
Irrigation Agriculture
Cropland Area
Pasture Land Area
Crop Diversity
Crop Ratios
Cropping Choice
Cropping Intensity
Crop Yield
Seed Variety
Water Delivery System Efficiency
Livestock Production
Livestock Access to Water and Grazing Area
Rate of Development of Irrigation
Irrigation Costs
Management Costs
Maintenance Costs
Equipment/Fuel Cost
Capital Intensity
Government Subsidy
Per Capita Income
Employment
Input Cost
Input Availability
Perimeter Design and Size
Perimeter Maintenance
Animal Traction

Socioeconomic Infrastructure

Marketing System
Credit
Production Input System
Communication System
Transportation System
Agricultural Extension
Management Centralization
Equipment Maintenance
Household Resources
Household Resource Allocation
Managerial and Technical Personnel
Milling Capacity
Storage Facilities
Pricing Policy
Labor Availability
Labor Intensity
Technology level
Land Tenure
Employment Opportunity
Risk
Agricultural Research

University of Michigan Gambia River Basin Studies, 1985.

systems numerous cost and technical factors influence the productivity of any particular scheme. Perimeter size, cropping intensity, labor requirements, capital intensity, and water delivery system efficiency are particularly important to irrigation agriculture schemes. Socioeconomic infrastructures -- such as management centralization or local control, marketing systems, production input systems, milling capacity, storage facilities, the availability of trained managerial and technical personnel, and agricultural extension and research -- are important to irrigation agriculture and the improvement of rainfed agriculture production.

4.2. Feasibility of Irrigation Agriculture Expansion

Changing environmental conditions and increasing population pressures necessitate a change from extensive (land surplus) agriculture to intensive (high productivity) agriculture in the Gambia River Basin. This requires fundamental changes in existing farming systems. Although in the long run irrigation will play an important role in agriculture, the transition period from current practices to irrigation systems is the primary consideration in our evaluation. At what pace and what rate should irrigation agriculture be introduced into the farming systems of the basin?

Our conclusion is that for the short and medium terms (less than 25 years), the rural populations predominantly will continue to depend on rainfed agriculture. Efforts during this time should be directed toward improving existing agricultural systems and laying the foundation for the transition from extensive to intensive agriculture production systems, which includes irrigation agriculture. Advance planning and development of agricultural systems to overcome current constraints to implementation of intensive agriculture are preconditions to massive development of irrigation agriculture. Allocation of resources to irrigation agriculture in the next several decades therefore should not come at the expense of efforts to improve rainfed agriculture and the agricultural infrastructure in general.

The gain in irrigation agriculture production as it exists has been less than anticipated because of technical, administrative, and structural constraints. Furthermore, production gains have been constrained as households limit their participation in irrigation schemes because of what they see as the risks involved.

- Inefficient water delivery systems are a major constraint to double cropping and proper crop husbandry.

- Member State governments do not have the capacity to train, supervise, and provision the number of agents necessary to achieve production goals.
- The existing marketing infrastructure is not equipped to handle the volume of current production.
- Limited transportation, storage, and communication systems and facilities reduce the flexibility of the system to respond to production and input distribution requirements.
- Limited local storage and milling capacity create significant bottlenecks to effective distribution and increase marketing costs considerably.

Irrigation models which assume the availability of free household labor seriously underestimate its availability. During critical periods, a labor constraint will exist; in addition, returns to labor may be insufficient to attract the labor required for intensive agriculture.

4.3. Irrigation Expansion Plans

The high expectations placed on irrigated agriculture's potential contributions to the goals of food self-sufficiency and import reduction are reflected in the OMVG Draft Indicative Plan projection of regional food balances based on different development scenarios.

4.3.1. Rainfed and Irrigated Agriculture Scenarios

The regional cereal supply and demand situation for the period 1982 to 2010 is projected for both rainfed and irrigation agriculture scenarios. The scenario based on improvements in rainfed agriculture assumes a fast rate of growth in production (between 0.7% and 1.5% per year, depending on the crop, resulting from increases in area and yields). In this scenario the basin moves from its current deficit situation to a greater cereal deficit of -156,000 metric tons a year by 2002. With a scenario based on development of irrigation agriculture, however, which assumes dam construction in order to allow for double cropping, the basin moves from its initial deficit situation in 1982 to a regional surplus of +104,000 metric tons by year 2002 and +232,000 metric tons in year 2010. According to this scenario a regional cereal surplus is generated when roughly 25,500 ha are in intensive double-cropped production. Based on the fast rate of implementation after construction of Kekreti, regional self-sufficiency is achieved in 20 years; and with the slow rate, in 30 years. This assumes yields of 4.5 tons/ha and a cropping intensity of 180 percent.

4.3.2. Suitable Irrigable Area

According to the Draft Indicative Plan the estimated net area available for irrigation development from the Kekreti Dam is 70,000 ha. This includes both first priority (involving no major development problems) and second priority (involving some development problems) land classifications. Of this net area approximately 53,500 ha are in The Gambia, and 16,500 are in Senegal Oriental. In The Gambia some 44,500 ha are identified as suitable for rice production, with the remaining 9,000 ha suitable for other cereal crops, vegetables and fodder crops. In Senegal Oriental the estimate of land suitable for rice production is 12,000 ha, leaving 4,500 ha for the irrigated cultivation of maize, sorghum, bananas, and vegetables. In addition, recent studies suggest that there are 15,000 irrigable hectares in the Guinea portion of the Gambia River Basin. The suitability of this land for different crops has not yet been determined. The total irrigable area in the Gambia River Basin, therefore, is approximately 85,000 ha. To date approximately 3,000 ha, 2,600 ha in The Gambia and 400 ha in Senegal Oriental, have been developed, mainly in small irrigated perimeters.

4.3.3. Rates of Expansion of Irrigation

Various rates for the expansion of irrigation throughout the Gambia River Basin have been proposed. The Kekreti Dam feasibility study proposed that 70,000 ha be developed during a 30-year period. LRDC has submitted a plan to develop 30,000 ha of irrigated area in The Gambia alone. Its plan includes both a slow and fast rate of development. The slow rate calls for the development of 30,000 ha in 54 years, where the annual development would range from 200 ha/yr to 1000 ha per year. The fast rate necessitates the development of between 600 to 2000 ha per year in order to develop 30,000 ha in a 34-year period.

The OMVG Draft Indicative Plan also contains fast and slow options for irrigation development for The Gambia, Senegal, and Guinea, reflecting the different physical, socioeconomic and infrastructural conditions found in the three countries. In The Gambia total development of the available 53,500 ha of irrigable land would take place in 55 years, while development of the available 16,500 ha in Senegal Oriental would require 55 to 60 years. A lack of information on the constraints to the expansion of irrigated agriculture in Guinea result in more modest development plans.

4.3.4. Irrigation Development Costs

The costs for irrigation development vary considerably, depending upon the degree of water control to be achieved, soil and site conditions, management and capital intensity, and the amount of infrastructural development necessary. Another important factor is the location of the perimeter and its distance from sources of inputs. Experiences with irrigation in Africa indicate that the costs for irrigation development based on capital intensive large scale perimeter development can range from $5,000 to $15,000/ha. On the basis of a conservative average investment cost of $10,000/ha, the development of the 70,000 irrigable hectares would cost roughly $700 million over 20 to 30 years. This cost does not include any dam construction costs.

4.4. History of Pump Irrigated Agriculture

Both The Gambia and Senegal are experimenting with pump irrigated agriculture, though Guinea has not. In addition, Senegal has had expensive experience, which predates independence, with pump irrigation and river basin development on the Senegal River.

4.4.1. Current Irrigation Projects

There have been four projects to introduce pump irrigated double cropped rice production in The Gambia. Three of these projects, the Taiwanese Agricultural Mission from 1966 to 1975, the World Bank Agricultural Development Project from 1973 to 1976, and the People's Republic of China Agro-Technical Team from 1975 to 1980, shared the objectives of introducing pump irrigated double cropped rice production on small perimeters from 5 to 20 ha. Construction of the Jahaly Pacharr pilot irrigation project began in 1982. The first year of production was 1983/84. The objective of this project is the development of 560 ha of double-cropped rice production using very capital and management intensive techniques.

In Senegal Oriental two projects currently being implemented have a pump irrigation component. The largest is the PISO (Perimetres Irrigués du Sénégal-Oriental) component of SODEFITEX (Société de Développement des Fibres Textiles), a regional development agency. This project was started in 1978; roughly 384 ha have been developed for the double cropped cultivation of irrigated maize and rice crops. The other irrigation development effort in the Senegal Oriental is

being implemented by OFADEC (Office Africain pour le Développement et la Coopération), a nonprofit, nongovernmental organization started in 1978. In this project irrigation is one component of a multifacited program which operates in 15 different villages.

4.4.2. Irrigation Expansion in Senegal River Basin

In discussing the potential for irrigated agriculture to contribute to the development goals of Gambia River Basin nations, it is useful to review the experiences of irrigation development on the Senegal River, particularly those of SAED (Société d'Aménagement et d'Exploitation des Terres du Delta du Fleuve Sénégal), the parastatal organization responsible for the development of irrigation on the left bank of the Senegal River. During the last 20 years, the Member States of OMVS (Organization pour la Mise en Valeur du Fleuve Sénégal) -- Mali, Mauritania, and Senegal -- have invested an estimated $724 million in river basin management and the expansion of irrigated agriculture. After several years of experience, SAED operated irrigation schemes are just beginning to overcome the same problems which constrain irrigated production in the Gambia River Basin: low yields, low cropping intensities, poor management and maintenance, and high production costs. The improved situation is due to both better internal management of SAED and a more favorable policy environment for irrigated rice.

Since 1965, SAED has been responsible for the development and maintenance of irrigated perimeters. By 1983/84 approximately 20,000 ha had been developed for total water control irrigation. The primary crop is rice, while secondary crops are tomatoes, maize, sorghum, and other vegetables. The existing irrigated area is divided between large-scale, capital-intensive perimeters (from 250 to 1,000 ha) and small scale, labor intensive perimeters (from 5 to 20 ha). Large-scale perimeters have proven to be significantly more expensive to develop and maintain than small-scale perimeters. Current estimates indicate that large-scale perimeters cost from $10,000 to $15,000 per hectare to construct while small-scale perimeters cost from $2,000 to $5,000 per hectare.

While productivity and economic performance have, in general, been higher on small perimeters than on large perimeters, the overall performance of irrigated agriculture has been disappointing when compared to the objectives of original development plans. The cropping intensity for all crops was estimated at 122% in 1983. In the past, the rapid deterioration of infrastructure and equipment has resulted in a rate of abandonment about equal to the rate of expansion. Average

rice yields on small perimeters have been 4.7 T/ha, while on large perimeters yields have ranged from 4.5 T/ha in the middle valley to 2.9 T/ha in the delta. In 1982, 74 percent of irrigated rice production was consumed by the producing household, mitigating against large quantities being available for urban consumers (which was the original intention of the large schemes).

The general conditions under which irrigation has been incorporated into farming systems and the institution of SAED itself have undergone significant changes in the last two years. First, household response to SAED irrigation schemes has become more favorable because of the increasing severity of drought conditions in the Senegal River Basin. Irrigated rice is progessively becoming the only option available to farmers, as no rainfed harvests were attained in either 1983 or 1984. If climatic conditions continue to deteriorate, this response could be relevant to the situation in the Gambia River Basin. Second, certain changes in government policy and SAED management have made rice a more profitable crop in the Senegal River Basin. These changes have included tighter financial management and better input delivery on the part of SAED and an increased producer and consumer price policy which has allowed for more favorable returns to labor.

In short, SAED's experience with irrigated agriculture over the last 20 years indicates that the expansion of irrigation agriculture faces technical, managerial, and policy constraints. It is evident, however, that SAED and the Senegalese government have used their experiences to improve the feasibility of irrigation agriculture. These lessons are directly relevant to expansion of irrigation agriculture in the Gambia River Basin.

4.5. Models for Irrigated Agricultural Development

Three irrigation models currently are being considered as pilot projects upon which future large-scale expansion could be based. Two of these projects, the Jahaly Pacharr Project in The Gambia and the PISO project in Senegal, are already being implemented. A third, the LRDC Bansang Nibras Pilot Project, is being considered for implementation in the Gambia.

The primary objective of the three models is the introduction of total water control irrigation, which permits the intensive double-cropping of irrigated crops. The Jahaly Pacharr model also includes the improvement of 950 ha of swamp rice, which will permit higher yields due to improved drainage and the use of inputs. In

the Jahaly Pacharr and Bansang Nibras projects, the only irrigated crop proposed is rice, while in Senegal Oriental irrigated crops include maize as well as rice.

The assumptions and characteristics of each model (Table 4.2.) are critical because of their importance in determining the social and economic viability of the model. Irrigation systems based on achieving total water control can be very expensive, both to build and to maintain. A key factor in the cost of those irrigation systems is capital intensity, which reflects the importance of imported equipment and personnel. The degree of reliance on centralized management is also a factor -- the further management of the perimeter is from the farmer, the greater the need for scarce management skills.

In order to generate the benefits necessary to cover high costs, the scheme must generate high yields. It is assumed that this can be achieved through the use of improved inputs and cropping intensities near 200%. Without considerable benefits early in its life to match the large investment costs, the project's economic feasibility will be diminished. This will be reflected in low to negative internal rates of return.

Another characteristic which influences the social and economic viability of an irrigation model is the degree of change required in the farming system. This is a qualitative measure of the magnitude of the reallocation of household resources, primarily management, labor and capital, assumed necessary in order to incorporate double cropped irrigation. Finally, plot ownership and livestock access represent important sociological factors. They are indicators of whether farmers are viewed as tenants or partners in the irrigation scheme and of the degree to which the farmers' other enterprises are accommodated in the model.

The Jahaly Pacharr and LRDC models can be characterized as capital-intensive because of the extensive use of imported machinery in land development and seasonal preparation activities. In addition, Jahaly Pacharr has a very centralized management system which leaves very few production decisions to the farmer. The project staff are responsible for all aspects of the operation of the water distribution system and for all decisions on maintenance, land preparation, and planting. Seasonal credit, repayable at harvest time, is made available to farmers. In general, the model assumes a high degree of change in household behavior as a result of the rapid reallocation of resources into irrigation (in terms of both capital and labor). This model does not permit user ownership of plots or livestock access.

The LRDC model also assumes a high degree of change in the farming system. Each compound is assumed to cultivate a 2.0 ha rice plot, which requires a total

Table 4.2. Model Assumptions and Characteristics

Assumptions	Jahaly-Pacharr		LRDC	PISO
	Irrigated	Improved Swamp		
Total Area Developed (ha)	560	950	928	384
Irrigated ha/compound	0.5	.95	2.0	R/0.25, M/0.06
Decrease in rainfed ha/compound	None	None	2.5	None
Cropping intensity	200%	100%	180%	130-180%
Yields tons/ha Dry-Wet Season	4.5-4.0	3.1	4.5-4.0	R/4.0, M/3.0
Labor man days/ha Dry-Wet Season	186-174	141	158-158	N/A
Capital intensity	High	Medium	High	Medium
Management Centralization	High	Low	Medium	Medium
Degree of change expected in household resource allocation	High	Low	High	Moderate
Own plot/livestock access	No	N/A	No	No

Note: Both Jahaly-Pacharr and Land Reclamation Development Consultants (LRDC) have several farm models upon which they base their calculations. This table presents the dominant farm model. Sources: Jahaly-Pacharr Smallholder Appraisal Report, IFAD 1982, Bansang-Nibras Pilot Project Feasibility Study (Draft), LRDC July 1984, and SONAD, 1980, vol. 2.

R: rice
M: maize

University of Michigan Gambia River Basin Study, 1985

annual allocation of 569 man days of compound labor. In addition, the compound is expected to give up 2.5 ha of groundnuts in order to produce rice. In order to cultivate this large irrigated area, most compounds are expected to purchase a pair of oxen and equipment for irrigated rice production (this technology has not yet been tested in The Gambia). While households are to participate in some management decisions, the scheme still requires a medium degree of centralized management. It also is capital intensive. This model does not consider individual ownership of plots and livestock access.

The PISO model has perimeters designed in terms of small-scale, labor-intensive, low technology. As such, they are less capital and centralized management intensive because more user participation is expected in development, management, and production activities. However, PISO management is still responsible for development, maintenance, and operation of perimeters as well as for the provision of technical support, provision of inputs through a scheme of seasonal credit, and membership training for self-management. The degree of change is moderate relative to the other two models. Users are not expected to significantly change their existing farming system.

4.6. Constraints to the Expansion of Irrigated Agriculture

For large-scale irrigation to be worth the resources it requires, double-cropping and high yields must be achieved and maintained. These are the key assumptions in the models described above. However, analysis of farming systems in the Gambia River Basin indicates that presently there are a series of constraints which must be resolved if these goals are to be achieved in the near future. These include water delivery system inefficiencies as well as structural, economic, and socioeconomic constraints which will limit the ability to achieve double cropping and the sustained high yields necessary for irrigation, especially capital intensive irrigation. These constraints, evident in the low production levels of existing irrigation systems, will be exacerbated with the expansion of irrigation as presently planned. In the short and medium term, irrigation development of the kind envisioned in existing proposals will generate the need for large and recurrent government subsidies.

4.6.1. Water Delivery System Efficiency

Inefficient water delivery systems in irrigated perimeters throughout the Gambia River Basin are a major constraint to expansion of irrigated agriculture.

Major causes of inefficient water delivery systems are poor perimeter construction, inappropriate equipment, and insufficient maintenance of irrigation systems. These inefficiencies contribute to system deterioration, low yields and cropping intensities, and possible perimeter abandonment.

Perimeter design, which includes the choice of an appropriate water delivery system and its construction, and maintenance, is a major factor in water delivery system efficiency and cost. Incomplete feasibility studies and construction result in poor identification of different soil types within perimeters, drainage problems, and unforeseen water losses due to seepage and evaporation. Inappropriate equipment choices and lack of funding for equipment repair and replacement, nonstandardized equipment, and lack of spare parts result in serious maintenance problems. This problem is exacerbated by the lack of maintenance personnel. Poor system maintenance, especially in the postinvestment period, creates water delivery irregularities which have a direct and negative impact on system costs, yields, and farmer participation.

In general, chronic problems with inefficient water management within perimeters has been a major reason for the low use rate and rapid deterioration of existing perimeters in the Gambia River Basin. Variations in soil conditions and contour within perimeters have resulted in problems of water distribution between plots. Unanticipated seepage from unlined canals and large water losses due to evaporation have resulted in high water extraction rates and pumping costs. The use of irrigation perimeters in the rainy season has been limited by failure to incorporate adequate drainage and flood protection systems.

Equipment failure has further weakened water security. Each irrigation project operating in the Gambia River Basin has introduced a different selection of equipment and machinery. The maintenance of this equipment has become a serious problem in the post investment phase due to a lack of critical local capability to maintain equipment. Adequate maintenance of machinery and equipment involved in irrigation presupposes the existence of trained mechanics, adequate supplies of spare parts, and adequate funding for repairs and replacement of equipment. This constraint becomes more binding as the technical complexity of equipment increases.

Perimeter size is also a factor in determining water delivery system efficiency. In theory, large perimeters (200-1 000 ha) can achieve economies of scale in water delivery; however, they require more sophisticated levels of technology,

management, and maintenance. SAED's experience with irrigation suggests that small perimeters (15-20 ha) which are labor intensive and based on simple technology achieve higher yields and cropping intensities than do large scale perimeters. The experience in The Gambia with small perimeters has, nonetheless, been poor.

The variation in agroeconomic conditions throughout the Gambia River Basin and the poor performance of irrigation to date suggest the need for further experimentation with perimeter design before large scale expansion of irrigation can be considered. Two of the proposed models, LRDC and Jahaly Pacharr, are large scale and capital intensive projects requiring the use of machinery and equipment not locally available. Jahaly Pacharr is based on the extensive use of large mechanized equipment for land preparation. While the management of Jahaly Pacharr has assured high maintenance standards in its first year of production, it remains to be demonstrated that these can be sustained. The LRDC model is based on the use of animal traction, which currently is not used in irrigation in the Gambia River Basin.

4.6.2. Structural Constraints

The lack of essential infrastructural and institutional capabilities could limit efforts to improve agricultural production. The lack of essential research and extension capabilities, a low capacity marketing system, an inefficient input distribution system, limited storage and milling capacity, and the lack of managers and technical personnel affect development programs for both rainfed and irrigated agriculture. However, irrigated systems depend more heavily upon these services for basic survival.

Research and extension. The key institutions necessary to support agricultural development are adequately funded and effectively functioning agricultural research and extension services. All three Member States have existing agricultural research and extension services. However, only limited agronomic testing of cereal varieties and cultural practices has been conducted on food crops in the region. As a result, only limited improvements are presently available to farmers for food crop production.

Recently, food crops have been given greater attention by agricultural research institutions in the Gambia River Basin. However, despite the new orientation, research capabilities remain limited. Research staff and budgets are limited. The significant variation in agroeconomic conditions throughout the basin compounds the

problem. Improvements in agricultural research capabilities are currently in progress in all countries, but significant results are awaited.

The development of intensive agricultural farming systems requires an effective agricultural extension service. Member State governments will need to develop the capacity to train, supervise, and provision the number of agents necessary to achieve the proposed irrigation expansion goals. LRDC estimates the need for 2 agricultural agents and 6 demonstrators per 1000 ha or irrigated area.

Existing extension services in the Gambia River Basin, however, suffer from several problems. In both The Gambia and Senegal, extension agents receive little specialized training. As a result, they are capable of providing only limited and narrowly focused assistance to farmers. A lack of funding for transportation and materials limits their contact with farmers. In addition, they are required to perform administrative duties associated with input distribution. Institutional barriers between research and extension services often block the development of critical linkages between these two services.

Marketing infrastructure. The existing marketing infrastructure is structurally limited in its ability to handle the increased volume of production envisioned in current development plans. The existing system is constrained by a lack of private sector involvement. The majority of private traders are involved in the distribution of imported goods to semiurban and rural areas and are only marginally involved in the marketing of domestically produced goods. In addition, the remote locations of many production areas and the small quantities of marketable surpluses inhibit the private sector. Serious storage constraints exist at all levels in the marketing chain. The lack of storage facilities are especially binding at the producer, milling, and wholesale levels. These constraints limit the flexibility of the system to respond to production increases.

Furthermore, there has been extensive government intervention in the marketing of export crops. In their effort to assure adequate food supplies at reasonable prices, government agencies and parastatals have also become involved in food crop marketing. Legal monopolies, licenses, and quotas limit private sector involvement in the distribution of imported and some domestically produced food crops, particularly rice.

In Senegal and The Gambia, government intervention in establishing official food grain prices in the past has reflected a consumer bias. This bias has encouraged the consumption of imported food and discouraged the production of

domestic foodstuffs. Official producer prices have not provided farmers with the incentive to increase production beyond their subsistence requirements. The subsequent decline in production has greatly reduced the traded surplus of food products. This decline in marketed surplus in conjunction with government marketing policies has weakened the marketing system by limiting private sector participation and by inhibiting use of the market mechanism to convey signals of supply and demand between producers and consumers.

Input delivery system. The capacity and reliability of existing input distribution systems must be significantly improved if they are to meet the needs required by current plans for increased irrigated agricultural production. The existing input distribution system of seeds, chemicals, machinery, and fuel does not supply farmers with the quality, quantity, and timeliness necessary to achieve desired production levels. The lack of availability of certain inputs can offset the usefulness of others, making it impossible to achieve optimal yields.

In The Gambia, the government has the dominant role in the provision of all inputs to irrigation perimeters. The Department of Agriculture and Department of Water Resources are responsible for water distribution, for fuel and oil for pumps, and for maintenance and repairs. The Gambia Produce Marketing Board (GPMB) has a monopoly on the import and sale of fertilizers and other chemical inputs. Unreliable input delivery has been a major factor in the low production and credit repayment levels observed in The Gambia. Due to an inefficient scheduling system, centralized workshop, and lack of spare parts, the demand for tractor power tilling services cannot be met. Erratic supply schedules of fuel and oil to irrigation pumps reduce the efficiency of the water delivery systems. The GPMB seems unable to supply users with the quantities of chemical inputs needed, especially at the appropriate time to fit into the precise cultivation practices associated with irrigation. An exception is the input distribution system for the Jahaly Pacharr project. There, project management so far has been able to assure adequate quantities and qualities of necessary inputs.

In Senegal Oriental, SODEFITEX and OFADEC are responsible for the distribution of inputs to farmers cultivating in their zone. In comparison to the situation in The Gambia, the SODEFITEX input delivery system has been more reliable. Supplies arrive on time, in sufficient quantity, and in good condition; their distribution among PISO participants is well managed. SODEFITEX receives its share of imported fertilizers, pesticides, and small experimental quantities of

herbicides from the Société Industrielle d'Engrais au Sénégal (SIES), which it then transports to distribution centers in the project zone. Fuel and oil are distributed to perimeters in sufficient quantities in time to assure the reliable operation of pumps. SODEFITEX is able to assure a reliable supply because of the well established input supply service established for cotton production. Production in OFADEC perimeters, however, is hindered by unreliable supply service.

Government controlled input supply systems in the Gambia River Basin, with the notable exceptions of SODEFITEX and Jahaly Pacharr, have not been able to provide farmers with an adequate supply of inputs necessary to achieve high production levels. Even when successful the input delivery systems have been able to provide only a narrow range of predetermined quantities and types of inputs and have not been able to respond to changing circumstances and variation in demand.

Cereal milling. Inefficiencies in rice milling and limited local storage facilities create bottlenecks to an effective distribution system and increase marketing costs. Rice milling capacity in the Gambia River Basin is, for the moment, more than adequate but poorly used. Presently, most domestically produced rice is hand-pounded for household consumption. This represents a major domestic activity for women. There is only limited local availability of small-scale rice mills in the Gambia River Basin. However, both The Gambia and Senegal have built large regional rice mills. The government owned and operated mill at Kuntaur in The Gambia has a milling capacity of 20,000 metric tons/yr, while the mill in Kédougou in Senegal Oriental has a milling capacity of 10,000 metric tons/yr. Both mills have been operating at low efficiency rates due to the small quantity of rice which enters official market channels.

Milling and storage constraints will create bottlenecks for several reasons. First, there are limited storage facilities at Kuntaur. Problems with grain spoilage already occur with the small amounts that are milled at this location. More important, however, centralized mills require complex and costly assembly and transport arrangements from producing regions. Given the scarce transport facilities available for output as well as input transport and distribution, the lack of more localized milling capacity represents a constraint. The lack of milling capacity for other crops, such as maize and millet, constrains increases in their production by creating labor bottlenecks in food preparation activities.

Lack of managers and technicians. Irrigated agriculture is a complex process requiring skilled management at every level of the process from perimeter design

through production, delivery of inputs, marketing, and processing. Existing perimeters in the Gambia River Basin (and SAED as well) have experienced shortages of experienced management personnel. The lack of management depth is a crucial barrier to improvement of agricultural production in general and irrigated agriculture in particular. Closely associated with this is the lack of technicians and mechanics capable of maintaining and repairing irrigation equipment.

4.6.3. Household Constraints

Constraints at the household level on individual participation in irrigation agriculture projects will impede achievement of development objectives. The amount of time available for project activities will be limited by the time individual family members devote to other responsibilities. Avoidance of risk also will constrain participation.

Labor availability. A labor constraint during short but critical periods in the agricultural production calendar currently affects area cultivated, cropping intensities, and cultivation practices of irrigated crops. In addition, labor often is not allocated to irrigation because individual family members view the returns to such labor as insufficient. This suggests that irrigation models which assume the availability of household labor may be seriously underestimating its availability.

Analysis of our labor data for three villages, Alunhari and Nema in The Gambia and Pakeba in Senegal Oriental, indicates that household labor, in an absolute sense, is not a scarce resource except during the labor intensive and critical periods of planting and weeding during the rainy season. During this period, however, labor is a constraint. Other than these periods, the labor data indicate that underused labor does exist, although it is not allocated to irrigation.

Irrigation development projects normally are predicated on the assumptions that labor units within a household are of equal capacity, that they are mobile between household activities, and they they are essentially free. These assumptions do not appear to hold. There are significant differences between younger and older men and between women and men with respect to their responsibilities in the household. Each of these groups has different sets of employment opportunities. During the dry season young men migrate from the village for various lengths of time in order to seek wage employment. For this category of worker, the opportunity cost of labor is potential wage employment. The attraction of wage labor is further enhanced because remuneration is immediate and paid to the

individual, which may not be the case in agriculture, especially for individuals working on collective family plots.

Risk. A critical factor limiting the incorporation of irrigated agriculture into basin farming systems appears to be the high risk associated with existing production techniques. The low level of participation in irrigated rice can be partially attributed to risk avoidance, particularly when farmers operate in an environment of uncertainly over input availability and cost. Farmer adherence to a risk minimization strategy is exemplified by the allocation of a significant proportion of cultivated area to lower yielding and less profitable rainfed cereal crops, as indicated by our field studies. Risk minimization strategies are also manifested in the diversification and multicropping of crops to accommodate annual variability in rainfall distribution and in the selection of crops requiring low levels of purchased inputs to minimize losses in case of crop failure.

4.7. Recurrent Costs and Subsidies

Efforts to expand irrigation will have important repercussions on the national economies of the Member States. The magnitude of investments necessary for irrigation expansion is large, especially when necessary dam construction costs are included. In addition to loan repayments for infrastructural development costs, the government must pay annual recurrent operation and maintenance costs and production subsidies.

Irrigation fees paid by users in existing Gambia River perimeters do not cover operation and maintenance costs, let alone infrastructural development costs. Estimates of capital investment and operation and maintenance costs per hectare for two existing irrigation projects, Jahaly Pacharr and PISO, illustrate this point (Table 4.3.). Annual operating costs include management, repairs, and replacement costs estimated on an annual per hectare basis. Annual users fees charged to farmers in 1983/84 for the two growing seasons are estimated to have been $350/ha at Jahaly Pacharr and $290/ha at PISO. These charges cover only water and machinery use. When the annual user fee is subtracted from the annual operation and maintenance cost, the per hectare unrecovered cost is $230/ha at Jahaly Pacharr and $330/ha at PISO. With 580 ha cultivated at Jahaly Pacharr and 181 ha at PISO, the annual unrecovered cost for Jahaly Pacharr represents an annual subsidy of $133,000 and for PISO $60,000. These unrecovered costs must be

Table 4.3. Investigation, Operation and Maintenance Costs of Irrigation Models

	Total Costs Per Hectare	
	Jahaly Pacharr	Piso
Capital Investment Costs/ha	$11600	$2000
Annual O & M Costs/ha	$ 580*	620
Annual User Fee/ha	350	290
Annual Subsidy/ha	$ 230	330
Total Unrecovered Annual Subsidy (current cultivation)	$133,000 (580 ha)	$60,000 (181 ha)

* Recent estimates for Jahaly Pacharr have lower per ha O & M costs; thus the annual subsidy could be less than our estimates.

University of Michigan Gambia River Basin Studies, 1985.

absorbed by the government if essential operation and maintenance activities are to be continued.

The unrecovered costs represent only one aspect of the current production subsidies to irrigated rice production. Subsidies also are being provided by the government for the purchase of certain inputs (Table 4.4.). Estimates based on recommended use of fertilizer, urea, and seed indicate the cost of these additional subsidies. According to these estimates the per hectare input subsidy for one season is $24 at Jahaly Pacharr and $85 at PISO. The annual unrecovered cost for Jahaly Pacharr is about $14,000 and for PISO over $15,000.

There is some discussion of eliminating all production subsidies in the near future. In view of our analysis, this is feasible only if producer prices are proportionately increased and if development and operating costs are minimized.

4.8. Agricultural Management Options

Constraints to the development of large scale irrigated agriculture in the Gambia River Basin lead us to question the dominant role given to rapid expansion of rice production in basin development plans. While irrigation agriculture will become increasingly more important in basin production systems during the next several decades, many steps need to be taken to alleviate these constraints before extensive expansion is undertaken. Suggestions for mitigation of the negative consequences of irrigation expansion and for improvement of existing agricultural infrastructures (Chapter 7) should be seriously considered. OMVG should establish as a priority the elimination of constraints to the development of intensive, higher productivity forms of agriculture.

In addition to the deliberate but measured development of irrigated agriculture, we recommend that other agricultural production systems and rural activities, such as livestock and fishing, be given greater emphasis in overall basin development plans. Improvements in agricultural production should be founded on existing agricultural production systems if they are to be successful. Given this perspective, in the short term existing rainfed and swamp rice agricultural production systems should be major foci of development activities. Means of incorporating irrigated agriculture into existing production systems could be an important area for subsequent research and planning by OMVG staff.

In addition, the creation of large reservoirs makes possible recession agriculture. Recession agriculture, practiced on the banks of reservoirs during the

Table 4.4. Production Input Subsidies During the Dry Season 1983/84

Inputs		Jahaly Pacharr			PISO	
		Subsidized Market Price	Actual Import Price		Subsidized Market Price	Actual Import Price
Fertilizer	115/kg/ha		$ 20	300/kg/ha	$ 35	$ 92
Urea	220/kg/ha	$ 35	47	300/kg/ha	30	55
Seed	50/kg/ha	15	7	40/kg/ha	5	8
Total Costs	$/ha	$ 50	$ 74		$ 70	$ 155
Annual Subsidy	$/ha	$ 24			$ 85	
Total Unrecovered Annual Subsidy		$13,920 (580ha)			$15,385 (181ha)	

Source: Market prices are those paid by farmers. PISO economic prices are prices to SODEFITEX.

University of Michigan Gambia River Basin Studies. 1985.

drawdown period, might provide significant hectarage for dry season agriculture with considerably less investment than proposed large scale irrigation production schemes. We estimate that the drawdown areas of Balingho and Kekreti will be 400 km^2 and 300 km^2, respectively. It is not known at this time how much of this land can be cultivated. In the case of Balingho, the problem of acid-sulfate soils could limit the amount of hectarage that can be cultivated. In the reservoir area of Kekreti, the steep slopes could limit the land available for recession agriculture.

Given limited resources available to the Member State governments, the management of the basins' agricultural sector will require decision makers to make trade-offs among the different development options discussed above. As currently envisioned, the large scale expansion of irrigation will reduce swamp rice hectarage and limit animal access to water. In addition, financial, managerial, and material resources allocated solely to irrigation will be diverted from other agricultural sector investment opportunities. In other words, the allocation of extensive resources into irrigation would be at the expense of investment in other forms of agriculture that could be more productive in the short to medium term.

In conclusion, we agree that irrigation agriculture will play an increasingly important role in food production for the population of the Gambia River Basin. However, irrigation models need to be improved significantly before they can be implemented on the scale currently envisioned in development strategies. OMVG and Member State planners could indeed learn an important lesson from farmers in the basin, who rely on a multienterprise, diversified farming system in order to minimize their risks. Given the significant natural and manmade risks facing the Gambia River Basin farmer, a multidevelopment option strategy seems essential.

5. FISHERY AND AQUATIC RESOURCE MANAGEMENT

Development of the Gambia River Basin essentially means manipulation of the environment for economic purposes. The primary purpose of basin development is to manage its water resources for hydroelectric power generation and irrigation agriculture. To do so will require extensive intervention in the hydrosphere and aquatic biosphere. The riverine portion of the aquatic biosphere will be considerably modified and the estuarine portion transformed.

The primary development actions that will directly affect the fishery and aquatic resources are the construction of dams, creation of reservoirs, regulation of streamflow, and the creation of a salinity barrier (Figure 5.1.). These will impact on the hydrosphere, the aquatic biosphere, and the fisheries. Secondary impact linkages also will be established, as impacts in the hydrosphere will alter the aquatic biosphere and these in turn will affect the fisheries. Additional impacts on the fisheries and aquatic resources will result from improvements in navigation, land and water management, agricultural management, and urban and regional planning. The effect of these impacts on achievement of development objectives will depend to a considerable extent on the fishery and aquatic resource management actions that are taken in response to the prospective impacts of the development actions.

The fisheries of the Gambia River Basin are important to attaining development objectives, especially for The Gambia. The fisheries provide an income to thousands of persons, are an important industry, and improve the balance of foreign trade. In addition, fisheries are an important source of protein for most of the basin population. The development projects will considerably affect the existing fisheries in The Gambia. Any impacts on the existing fisheries, therefore, will have important economic and nutritional consequences.

The fisheries also are an important indicator of the environmental quality of the aquatic resources. The standing crops of finfish and shellfish are a primary indicator of the nature of the impacts of human actions on the aquatic biosphere. Although the productivity of a water resource can be measured in terms of the amount of aquatic organisms (such as phytoplankton, zooplankton, and benthos), the most appropriate indicator is the standing crop of fish at the end of the food chain sustained by the body of water. Concern for the productivity of the fishery, then, is an important management concern in basin development.

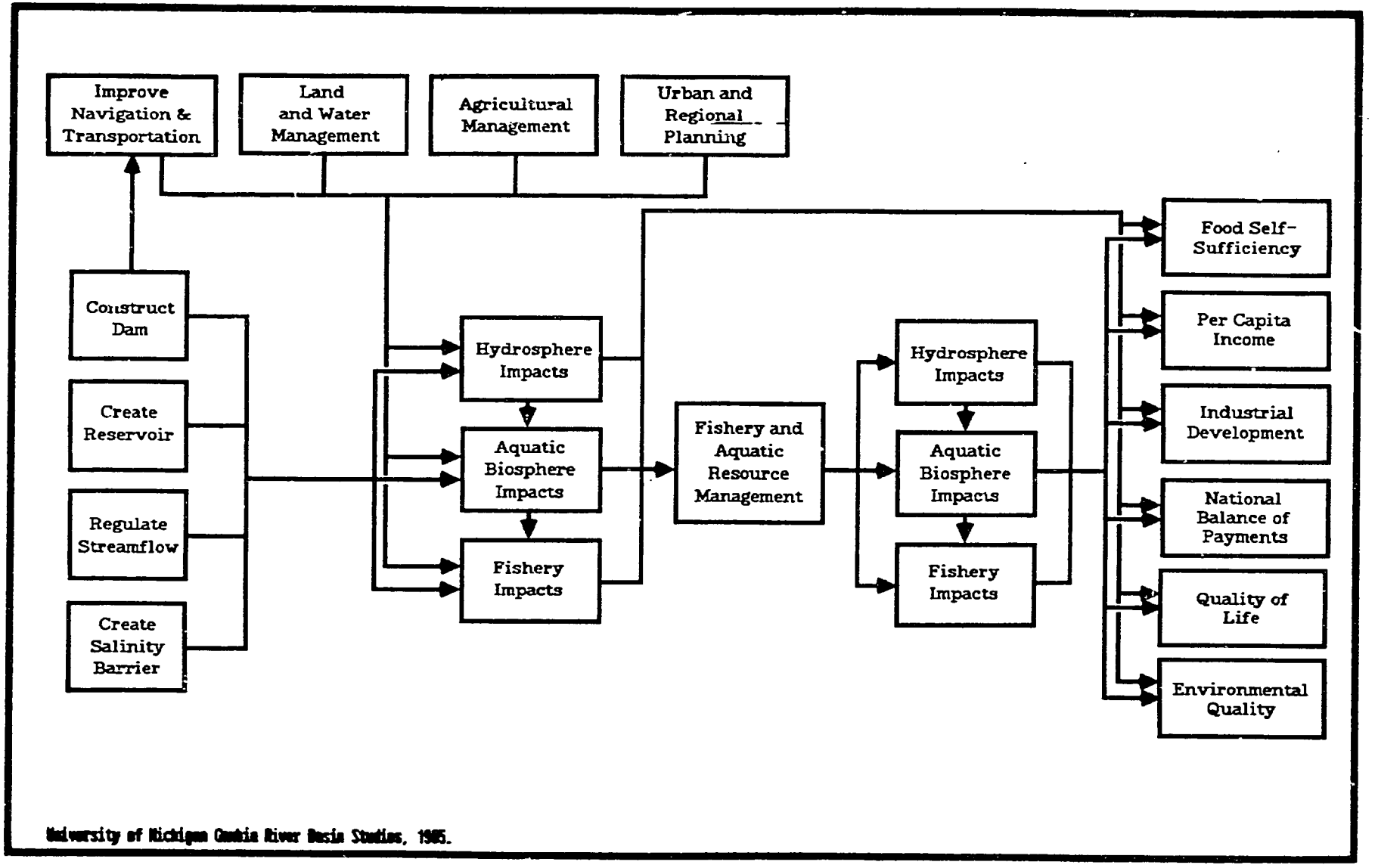


Figure 5.1. Fishery and Aquatic Resource Management Network.

5.1. Fishery and Aquatic Resource Management Impacts

As discussed in Chapter 3, the development actions will significantly modify the water resources of the basin. In terms of the aquatic resources themselves, the result will be to enhance the freshwater fishery of the basin by the creation of a lacustrine environment (e.g., man-made lake environment) at the expense of the existing estuarine and riverine environments (Figure 5.2.).

These environmental changes will significantly affect the fisheries in the basin. The creation of reservoirs will create a freshwater fishery potential of considerable benefit if effectively managed. This will be a new type of freshwater fishery heretofore unknown in the basin, as lake or still water fishing is considerably different from river or flowing water fishing. This potential, however, will be created at the expense of the existing estuarine fishery in The Gambia and, to an some extent, of the marine fishery offshore. Although the riverine fishery will be considerably diminished, the effect of this on total fishery production will be minimal.

5.1.1. Impact Attributes

The impacts of development projects on the fishery and aquatic resources of the basin can be described in terms of attributes in both the aquatic biosphere and socioeconomic production systems (Table 5.1.). The impacts of development actions on the hydrosphere, as discussed in Chapter 3, will considerably affect the attributes in the aquatic biosphere that are important for the standing crops of fish. The productivity of the fisheries will depend on the standing crops as well as on socioeconomic factors.

In the aquatic biosphere the standing crops of fish and shellfish will depend on impacts to such attributes as habitat, spawning and nursery grounds, migration paths, and species composition. The impacts will also affect the food chains supporting the fish, so fish food organisms, organic nutrients, inorganic nutrients, and pollutants are important. Impacts on biological attributes such as aquatic weeds and water-associated disease vectors have socioeconomic implications as well as implications for the quality of life of the human populations in the basin.

The productivity of the fisheries will be measured in terms of various socioeconomic attributes in addition to the production of the commercial, artisanal, and subsistence fisheries. Fishing effort and costs, per capita income, and export income are important for cost/benefit analyses of the fisheries. Fishery industries

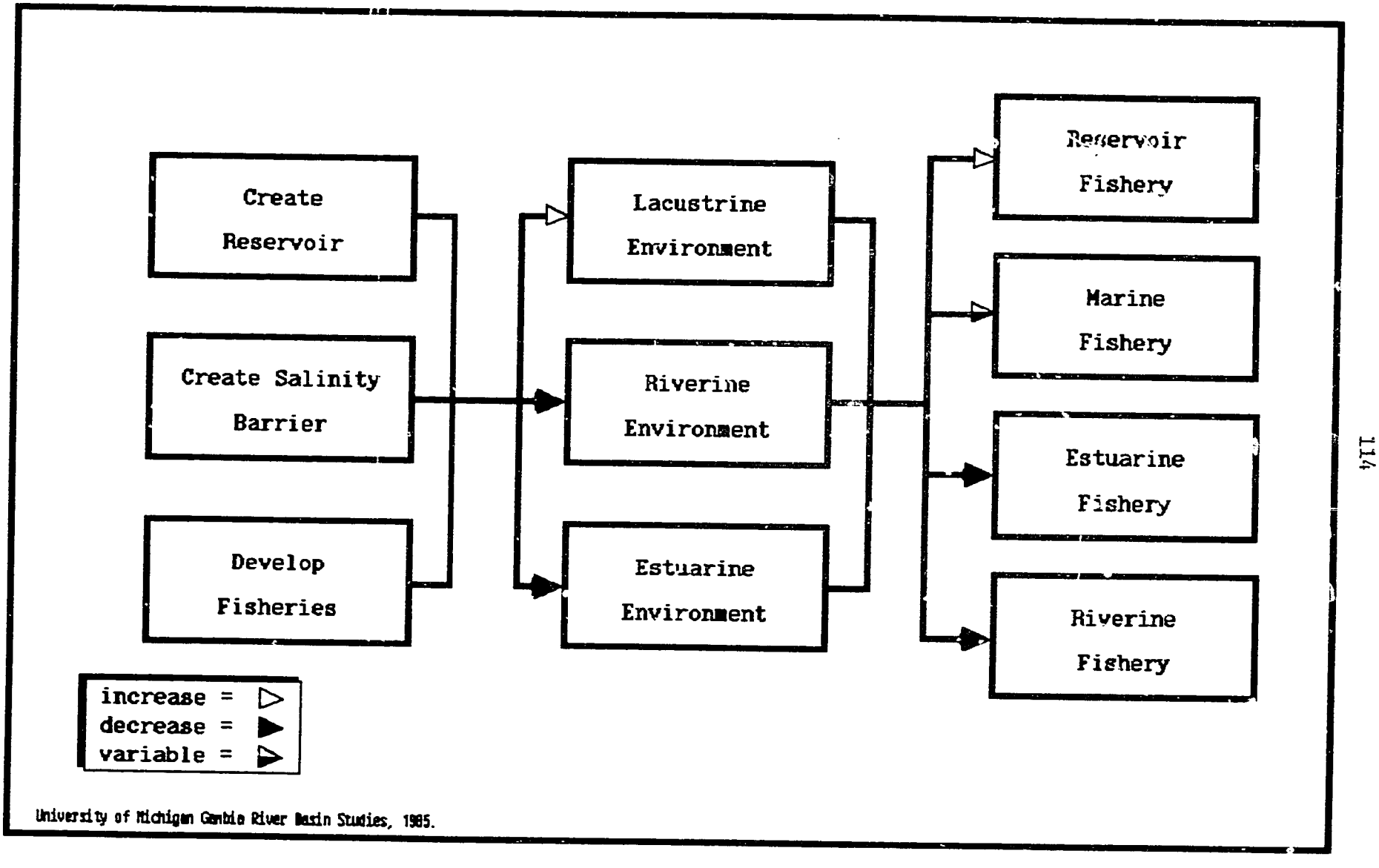


Figure 5.2. Fishery Tradeoffs of Basinwide Development

Table 5.1. Fishery and Aquatic Resource Management Impact Attributes

Aquatic Biosphere

Lacustrine Fish Standing Crop
Riverine Standing Crop
Marine Standing Crop
Estuarine Standing Crop
Fish Habitat
Shellfish Habitat
Fish Spawning and Nursery Grounds
Fish Migration
Fish Species Composition
Fish Food Organisms
Organic Nutrients
Inorganic Nutrients
Organic Pollutants
Inorganic Pollutants
Aquatic Weeds
Evaportranspiration
Aquatic Vertebrate Habitat
Water-Related Human Disease Vectors
Water-Related Livestock Disease Vectors

Socioeconomic Production

Commercial Fishery Production
Artisanal Fishery Production
Subsistence Fishery Production
Fishing Effort
Fishery Costs
Aquaculture
Fishery Processing Industries
Fishery Product Industries
Employment
Per Capita Income
Export Income

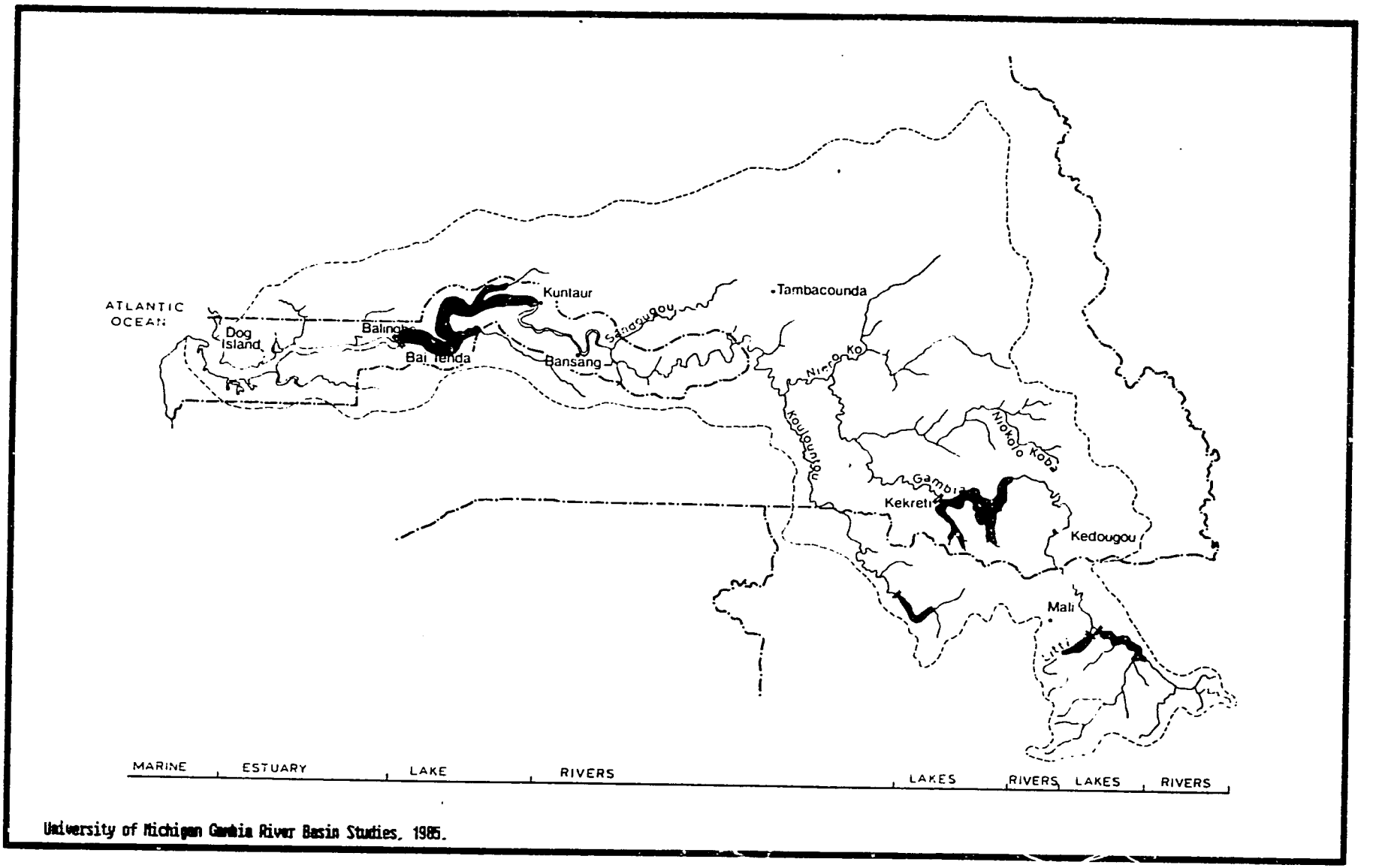
University of Michigan Gambia River Basin Studies, 1985.

will develop and can be monitored as indicators of economic progress. Aquaculture is an attribute that has considerable fishery management potential, as discussed in Chapter 7.

5.1.2. Modification of the Water Resource Map

In order to identify the various impacts of development actions on the fisheries of the basin, we find it relevant to explain how the water resources of the basin will be fundamentally changed. For the purposes of this analysis we divide the river into several zones. First, there are the zones ranging from entirely saline to slightly saline. These are the marine offshore environment; the highly saline lower estuary from the ocean to Mootah Point (about river km 60), where the influence of fresh water is not observed; and the upper estuary from Mootah Point to Kuntaur (river km 251), where saltwater and fresh water intermix -- its boundary being defined by the extent of the salt tongue intrusion according to the season. Second, there are the freshwater environments upstream from Kuntaur -- the various flowing water or riverine environments. These consist of a lower freshwater zone where the slow flowing Gambia River has distinct tidal mixing, which extends upstream to Gouloumbou (river km 510); an upper freshwater riverine zone from Gouloumbou to the Guinea border (river km 970), where there is a distinct seasonality in the riverine characteristics; and a headwater zone in Guinea from the border to the source at Ore Dima (river km 1,100), where there is a network of relatively small rivers and streams as well as a sharp elevation drop through the mountains.

This environmental or water resource regime will be considerably modified by river basin development (Figure 5.3.). The marine environment will be unchanged physically, although some of its attributes will suffer impacts. The upper and lower estuaries, however, will no longer exist. A new estuary -- almost an arm of the sea -- will extend from the ocean to Balingho dam at river km 128. The physical characteristics of this estuary will be quite different from those of the previous estuary, as discussed in Chapter 3. The estuarine aquatic biosphere, therefore, could be significantly changed. The upper estuary will be eliminated, as Balingho dam will block intrusion of saltwater farther upstream. Similarly, there no longer will be a significant distinction between the lower and upper freshwater riverine zones. The lower freshwater riverine zone will be considerably altered, as Balingho dam will eliminate the tidal mixing which provides its distinctive hydrologic characteristics. A new riverine zone will be created between Lake Balingho and Kekreti Dam, distinguished by the controlled streamflow from Kekreti. A similar



University of Michigan Gambia River Basin Studies, 1985.

Figure 5.3. Modification of Water Resource Map by Development Actions

riverine zone will be created between Lake Kekreti and Kouya Dam. The headwaters zone will become a system of rivers and lakes. About 200 km of the Gambia River -- almost one-fifth of its length -- will be changed to lakes, that is, to new lacustrine environments.

5.1.3. Summary of Impacts in the Aquatic Biosphere

- Estuarine nutrients. The dam at Balingho will block the flow of considerable nutrients into the estuary and offshore waters. It also will create a confined estuarine system susceptible to serious pollution. The combined result will be to reduce the aquatic productivity of the estuary and coastal waters.
- Lacustrine environments. The five lakes will create lacustrine environments that will benefit from nutrients retained by the dams. These environments could have a thriving aquatic productivity. They will be susceptible to excessive nutrient accumulation, however, which would reduce aquatic productivity. Water quality could become a problem.
- Remaining riverine environments. The remaining riverine environments will preserve their basic biological integrity. However, the elimination of seasonal flooding and tidal flooding will completely change the hydrology of the river. This may reduce riverine aquatic and fish productivity.
- Fish migration and habitat. Important fish migration paths, especially for bonga and shrimp, will be blocked by Balingho. The loss of mangrove forest due to Balingho will significantly reduce fishery productivity. The loss of the salinity gradient could reduce the shrimp stock and catch in the estuary.
- Fish species composition. Shellfish will be eliminated above Balingho, along with most marine and estuarine finfish. Lacustrine freshwater species will thrive. The fate of migratory freshwater species is uncertain.
- Fish productivity. Shellfish productivity will be diminished. Some marine finfish productivity could be enhanced, although other marine and estuarine finfish productivity will be lost. Reservoir fish productivity will be substantial.

5.1.4. Summary of Impacts on the Fisheries

The maximum total annual fish catch potential for the reservoirs is estimated to be 7,500 tons a year, provided there is effective fishery management. The gross annual value of this fishery will be $7,500,000. (The net value will be considerably lower, and distribution and marketing limitations could further reduce the value of the fisheries.)

Gross Value of Reservoir Fisheries		
Lake Balingho	5,600 tons	$5,600,000
Lake Kekreti	1,400 tons	$1,400,000
Guinea Lakes	475 tons	$ 475,000

- Impact of Balingho Dam on current Gambian fisheries. The catch potential of Lake Balingho might offset the losses to the catch potential of the existing fisheries. The annual losses to existing marine, shellfish, and estuarine fisheries could range upwards of $1,400,000 as a result of negative environmental impacts on fish productivity.

Losses to Current Gambian Fisheries	
Freshwater fishery* (100%)	$250,000
Shellfish fishery (50%)	$750,000
Estuarine fishery (30%)	$100,000
Marine coastal fishery (10%)	$300,000
*below Kuntaur	

- Net annual value of Lake Kekreti and Guinea lake fisheries. The production of the reservoir fisheries on Lake Kekreti and the Guinea lakes will be a net gain, as current riverine fishery production is minimal. The net value of the fisheries takes into account management and production costs.

Net Annual Value of Fisheries	
Lake Kekreti	$ 881,000
Guinea lakes	$ 274,000

- Aquaculture potential. Development actions will create the potential for various types of aquaculture.

5.2. Impacts in the Aquatic Biosphere

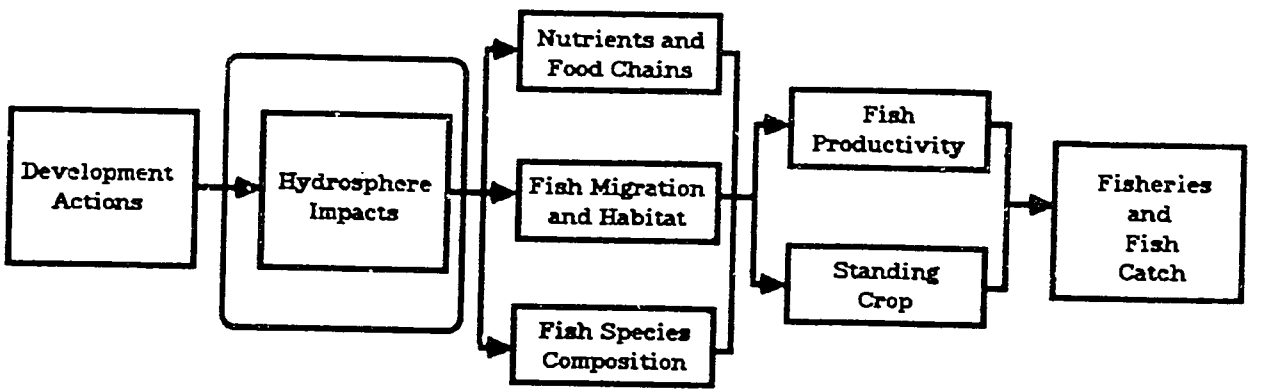
The aquatic biosphere will be modified throughout the Gambia River Basin by development actions and by subsequent impacts on the hydrosphere, as explained in Chapter 3. From the viewpoint of the fisheries, the impacts in the aquatic biosphere will form a network that ultimately will affect the fisheries and the fish catch (Figure 5.4.). The nutrients and food chains will be changed; the fish habitats and spawning grounds will be modified; and the fish migration paths and species compositions affected. These impacts will lead to changes in fish productivity and standing crops and, thus, in the catches of the fisheries.

5.2.1. Impacts on Estuarine Nutrients

Estuaries the world over -- especially those in tropical systems with extensive mangrove forests -- are among the most biologically productive of all ecosystems. In the Gambia River Basin, the estuary may lead all other aquatic and terrestrial ecosystems in the annual quantity of plant material produced naturally per unit area. After the Balingho Dam is built, this will no longer be so -- the aquatic productivity of the estuary will be significantly reduced.

The flow of nutrients into the estuary will be reduced primarily because of the loss of mangrove forest upstream of the dam and the thinning of the mangrove forest just below the dam. In addition, the estuary currently is the drainage sump for the entire basin. Balingho will eliminate this fundamental characteristic of the estuary because the downstream freshwater flow will end at the headwaters of the lake. Thus the nutrients and organic debris that now come downstream will be retained and recyled upstream in Lake Balingho. This loss of nutrients will lessen biological production in the estuary at all levels of the food chain.

The productivity of the adjacent coastal waters probably will also be affected by the loss of nutrients. Some of the nutrients entering the estuary now make their way offshore and sustain the productivity of the adult pink shrimp, which is the primary export crop of the Gambian fishery. The highest concentrations of pink shrimp are likely to be found on the sediments containing a high organic matter content around the mouth of the Gambia River estuary, coming from the present estuary and the river during the wet season. Thus, the reduction in nutrients will reduce shrimp growth and the size of the adult offshore stocks. As these are their spawning grounds, the productivity of the shrimp also will be diminished.



University of Michigan Gambia River Basin Studies, 1985.

Figure 5.4. Aquatic Biosphere Impact Network

The reduction in nutrient flow will affect the coastal cuttlefish population in a manner similar to the pink shrimp. The cuttlefish spawn over the offshore sediments containing the detritus deposited by the river. As this area will be reduced, the productivity of the commercially important cuttlefish also will be reduced.

In addition to diminishing the nutrients in the estuary, Balingho Dam will increase the potential for serious pollution of the estuary. Any flushing will be due to tidal action and rainfall in its own limited watershed. Pollutants, therefore, will be retained longer in the estuary rather than flushed out to sea at present rates. Although tidal mixing will remain a powerful force, in time the estuarine waters may become unsuitable for some forms of estuarine and marine life: marine and shellfish productivity, especially shrimp productivity, is particularly sensitive to pollutants. Toxins in pollutants furthermore accumulate up the food chain and render many fish and shellfish unfit for human consumption. In the long run, such pollution could affect the commercial fishery and human health considerably.

Currently, the principle sources of estuarine pollution are in the greater Banjul metropolitan area in Kombo North district. City storm water runoff, direct sewage and waste water outfalls, and accidental spills and dumping at the port pollute the estuary. A particularly insidious source of pollution is unwise solid waste disposal by bolon filling, as exemplified by the Banjul city dump on a bolon of the Oyster Creek system, where pollutants can leach and drain with tidal flushing into the estuary. Industrial development in and around Banjul is a potentially serious source of pollution. Current pollution will be amplified and the impacts become more noticeable when Balingho blocks the downstream flow that helps flush the estuary.

5.2.2. Creation of Lacustrine Environments

Whereas the estuary and offshore environments will be screened from nutrient enrichment, Lake Balingho and, to some extent, Lake Kekreti will benefit from the nutrients they trap. Lake Balingho will benefit from nutrients flowing in from most of the basin watershed, and Lake Kekreti will benefit from nutrients from much of the remaining watershed. The Guinea lakes will not profit as much because their watersheds are smaller, and the rivers and streams not as nutrient-rich as those further down.

The lacustrine or lake environments that will be created should provide suitable forage bases for reservoir fisheries. These environments provide expanded habitat for many species that cannot thrive in flowing water. New aquatic communities will

develop both in the water column and on the bottom of the reservoirs, especially in shallow areas. The result will be to create new food webs that will make the lacustrine fisheries more productive than the existing riverine fisheries displaced.

The water quality and forage base of a reservoir depend on a series of physical, chemical, and biological impacts that result from construction of a dam and other human activities as well as from environmental changes and nutrient enrichment. Some of these impacts enhance the quality of the forage base, although others can degrade it.

The reservoirs benefit from an increase in nutrient load that results from development projects as well as from watershed drainage. Riverine and rainwater drainage into a reservoir carries dissolved nutrients, such as nitrates, phosphates, and silicates, from the land, forests, and villages. This drainage is supplemented by the irrigation drainage enriched with nutrients from fertilizer used in agriculture. It is further enriched by the organic debris or detritus from the land vegetation that decays in the water. Organic human wastes and waste water as well as livestock wastes also enrich the forage base.

This rich nutrient base in a lake enhances the plant and animal organisms or biota, which form the food web leading to fish. It is supplemented by production within the reservoir itself, as the standing water of a lake is more favorable to most algae than is flowing water. The algae are the first link or primary producers in the food web. They also are valuable in that they take up carbon dioxide, toxic to fish, and release oxygen to the water for the fish and other aquatic animals.

The nutrient base can become overly rich, however, and degrade rather than enrich the water quality. Up to a certain extent, the nutrients will enrich the water. Past that, the water quality will decline. Algae can become superabundant and form floating mats. Algal decay can cause an oxygen deficiency leading to a mass mortality of fish. Algal mats can plug screens at water intakes of pumps; they also provide good habitats for disease vectors such as mosquitoes and snails. In addition, water plants and weeds can become overly dense. Rather than contributing to the richness of the water environment for the fish, they cover extensive areas; choke the reservoir and make large areas uninhabitable to fish; lock up nutrients needed for fish productivity; interfere with the use of fishing gear; impede navigation; and interfere with irrigation systems. In some reservoirs, the weed mats become so dense that access to the water from the shore is completely prevented. However, up to a certain limit of density they augment the substrate for fish feeding.

As important, perhaps, excessive nutrients hasten the filling and aging processes (eutrophication) of a reservoir. Organic plant material settles on the bottom and decays, consuming the oxygen so that the bottom layer of water becomes anoxic (without oxygen) and therefore diminishes the volume of the productive standing water in the reservoir. The bottom of a reservoir may become a constantly expanding layer of dead water, with seasonal variations.

The water quality in a reservoir, as in the estuary, will be further degraded by the infusion of pesticides and other toxic wastes from human activities. The implementation of irrigated agriculture inevitably results in the use of pesticides and herbicides. Some of those commonly used in developing countries (but restricted and banned in developed countries) persist in the environment for many years. They are transferred and magnified up the food chain and, being fat-soluble, accumulate in many fish and animals. The people living in a development region increasingly use insecticides against mosquitoes and other insect vectors of human disease. Public health control measures introduce vector control toxicants to kill schistosomiasis snails. Water management may require herbicides to control aquatic weeds; some chemical control of water weeds is also useful in snail control through reduction of the preferred habitat. Mining, as discussed in Chapter 3, also can contribute toxic metals and noxious salts, as well as acidify the water, in the reservoir environment.

5.2.3. Remaining Riverine Environments

The remaining riverine environments will more or less preserve their basic biological integrity, despite noticeable effects of changes in hydrologic regimes. The changes in hydrologic regimes in general will diminish the amount of nutrients that naturally enrich the water resources of the basin. Some slight effect of this will occur in the riverine environments, but the primary effect will be to diminish the amount of nutrients that accumulates in Lake Balingho. As Lake Balingho will become nutrient-rich in any case, the overall effect may be minimal in terms of that lacustrine environment.

The elimination of seasonal flooding and tidal flooding will reduce the downstream movement of nutrients in the river. The annual flood currently enriches the river with nutrients from the soil and decay of drowned vegetation. The tidal action now results in a twice-daily reversal of the direction of river flow, which slows the downstream drift of organic and other aquatic nutrients. It also accelerates the flushing and mixing of nutrients, contributed by the mangrove

swamps and the tributary bolons. Without the flushing, these nutrients as well as associated sediments will remain trapped in the bolons. The bolons will quickly silt up and no longer serve as pathways for the exchange of material between the floodplains at the end of the bolons and the river channel. Stagnation will characterize many parts of the riverine system, especially the mangrove bolons above Balingho.

The loss of annual flooding will further diminish fishery productivity because the floodplains along the river are the breeding and nursery grounds of many freshwater fishes, including the carp relatives and several catfishes that make lateral migrations into them to spawn. Because the food of the young is largely composed of microscopic organisms that explode in numbers due to the rapid release of nutrients to the water from the flooded soil and the decay of drowned vegetation, an extensive nursery will be lost.

Regulated streamflow as well as improvement of river navigation also will affect the riverine environments. Regulated streamflow will enhance erosion of the riverbed and banks, which will increase the turbidity of the water and induce instability in the riverbed, thus reducing overall biological production. Improvement of river navigation will have the same impact, as increased traffic as well as channelization and dredging will increase the turbidity and turbulence disruptive to the bottom-food organisms of fish. These actions also will disrupt and cover riverine fish spawning areas, further diminishing productivity. At the same time, maintenance of flow during the dry season will expand the habitat for riverine fishes as well as increase biological production, such as of aquatic insects on which fish feed, on the then permanently water-covered sand and gravel bars and banks.

The net result on riverine fish productivity is somewhat unpredictable. The current and potential standing crops of fish in the riverine environments, in any case, are considerably lower than the standing crops that will be established in the nutrient-rich lacustrine environments, as discussed below.

5.2.4. Impacts on Fish Migration and Habitat

The concerted effects of development actions will interrupt fish migration paths and practices, and the loss of mangrove will eliminate an important fish habitat. The production of the marine fishery will be the most significantly affected, although the artisanal fishery in the estuary stands to lose some of its catch.

The dam at Balingho will bar the upstream migration of invertebrates, especially shrimp. Currently, shrimp larvae grow into juvenile shrimp in the fertile grounds of the mangroves, including the 8,700 ha upstream of Balingho. The crab population, which now is very abundant near Jappeni, will disappear from there as well. In addition, the oyster crop, which flourishes on the roots of the mangrove, will be eliminated upstream of the dam. An extensive area of the present estuary will no longer be available for migrants.

In addition to the invertebrates, many marine finfishes now penetrate the Gambia River as far as Kuntaur and even beyond. We collected many species of estuarine species in the upper estuary. They feed and grow in the river, so their catch potential in the residual estuary will be noticeably reduced when the dam prevents their migration upstream. The most abundant river fish has been a herring, locally termed the "bonga," which long has been the mainstay of the artisanal fishery and the low-cost consumer food supply of the lower river and estuary. As food supply, it is the dominant species of the standing crop of fish supporting this fishery. Its anticipated reduction in the estuary will be an important factor in the lives of many fishermen and will work hardship on the prevalent low-income consumers.

The loss of the salinity gradient in the estuary will reduce the migration of the postlarvae of the pink shrimp into the estuary, which will reduce the sizes of the commercially important juvenile and adult populations. The postlarvae of the pink shrimp require the shallow estuarine environment to mature into juveniles. One of the mechanisms by which the young larvae are attracted to the estuarine water is the salinity gradient. The flood waters entering the estuary during the wet season increase the salinity gradient (the estuary becoming less saline, so the difference in salinity between the ocean and the estuary is increased) and thereby attract the larvae into the estuary. This, of course, increases the estuarine juvenile shrimp stock, which develops quickly from the larvae. The shrimp stock and average size of individuals composing it therefore may be reduced with the elimination and/or reversal of the salinity gradient.

Should hypersalinity develop -- which seems probable, at least locally -- the shrimp fishery productivity could be drastically reduced. When hypersalinity develops and the saline gradient becomes reversed, the larvae receive mixed signals and the juvenile shrimp migrate back to the ocean smaller in size. When this situation occurred in the Casamance, the shrimp catches (in 1984) were so mediocre

in quality and quantity that two shrimp processing plants near Ziguinchor had to close.

An additional loss of shrimp productivity will occur if the loss of fresh water, permanently high salinities, and tidal amplification in the estuary negatively affect the remaining mangroves below Balingho. The young shrimp would lose further habitat -- in addition to the 12% lost above Balingho -- and food source as well as cover and protection from predators provided by the intricate roots of the mangroves. The juvenile shrimp population would decrease.

Similar losses in oyster and crab productivity can be expected in the estuary. Any decrease in mangroves will decrease the attachment base for feeding and growth of oysters. In addition, the increase in salinity will favor the marine oyster drill snail, an oyster predator adversely affected by wet season inflows and reduced salinity. Crab production, currently used only for local subsistence consumption and the resident foreign and restaurant trade, will be reduced because it is enhanced by low salinities. The lack of a negative salinity gradient also will reduce the migration of crabs into the estuary from the coastal waters, so fewer will be available for harvest.

5.2.5. Impacts on Fish Species Composition

The fish species composition will change in various parts of the water resource system. Upstream of Balingho the marine invertebrates -- shrimp, crab, and oyster -- will be eliminated. Marine and estuarine finfish species probably will disappear as well, as the marine plankton on which they feed will be eliminated. Although certain marine and estuarine fish species can make a temporary transition to fresh water, they probably will not survive if they are permanently removed from their accustomed estuarine-based food chains. Upstream from Balingho Dam, the fish crop will become exclusively composed of freshwater species. Lacustrine or still-water species will be favored by the new lake environments, at the expense of riverine species.

5.2.6. Impacts on Fish Productivity

Changes in habitat, forage base, migration patterns, and species composition will alter fish productivity in the various aquatic environments. In contrast to the changes discussed above, such as the potential loss of shrimp and bonga, enhanced productivity can be anticipated as well.

The lower estuarine portion of the Gambia River is the most productive area of the river, for both finfish and shellfish. The rich nutrients of the estuary attract many coastal species. With the construction of the dam at Balingho, this habitat will be expanded. Allowing for a reduction in nutrients because of the dam, the expansion in marine habitat should lead to an expansion in productivity of some of these species, even though the productivity of species preferring a brackish water habitat will diminish.

More important, however, could be the increased fish productivity in the reservoirs. Reservoir fisheries are far more productive than riverine fisheries, so the increased fish yields from the reservoirs will offset the losses from the riverine, estuarine, and some marine fisheries. Fish yields from the reservoirs could contribute to the goal of domestic food self-sufficiency.

The reservoirs will provide a suitable environment for a variety of crayfish, mollusks, and other small invertebrates as well. A large and diverse benthic (bottom) habitat will exist in the shallow portions of the reservoirs. The habitat will be expanded by irrigation practices which will inundate large amounts of shrubs along the edges of larger irrigation canals. The expanded invertebrate productivity will stimulate additional fish productivity as well as provide an additional harvest crop for fishermen themselves.

5.3. Impacts on the Fisheries

The resulting impacts on the basin fisheries of the development projects are difficult to predict because the environmental impacts of development actions cannot be projected in quantitative terms. Despite losses due to impacts in marine species, expansion of the marine fishery in the extended lower estuary seems probable, but not easily quantifiable. Loss of some pink shrimp catch seems certain, but the extent of the loss could range to 50% of the current catch, depending on the impacts of Balingho dam on the estuarine environment. Development actions in general will create a productive reservoir fishery; marginally affect marine finfish production and decrease marine shellfish production; decrease the existing estuarine fishery; and decrease the riverine fishery (Figure 5.2.), if a constant fishing effort is assumed. Commercial, artisanal, and subsistence fishing will be affected.

The economic question is whether or not the establishment of reservoir fisheries will offset losses to the marine, shellfish, and estuarine fisheries. This

question arises only with reference to The Gambia. In Senegal and Guinea, commercial fishing does not exist within the basin, while artisanal and subsistence fishing production is minimal compared to the reservoir fishery potential. For example, our market analysis indicated that in the Senegalese portions of the Gambia River from Niokolo-Koba National Park to the Guinea border the annual catch is probably less than 15 metric tons.

5.3.1. Reservoir Fishery Potential

The maximum fish catch potential of the five man-made lakes or reservoirs proposed for the Gambia River Basin is about 7,500 tons a year (Table 5.2.). Most of this potential is in Lake Balingho, which could produce up to 5,600 tons of fish a year if the fishery is effectively managed. Although significantly less, the potential of Lake Kekreti -- about 1,400 tons a year -- is important because any production there will be almost a net increase in fish catch, considering that the current catch is considerably less than 5% of that. The potential of the Guinea dams is about 475 tons. Assuming a value of US$1/kg, the annual reservoir catch potential represents a $7,500,000 gross value at current prices. (This figure must be taken with considerable caution, however, as it assumes that the maximum potential can be realized and that effective marketing and distribution systems can be developed.)

Our estimates assume modest managerial inputs because effective development of reservoir fisheries requires fishery management. At present, effective fishery management -- especially of marketing and distribution -- does not exist. Fishing techniques and equipment such as type of net will have to change as traditional flowing water methods are impractical for still water fishing, especially in man-made lakes with obstructions and poor water quality on the bottom. In addition, a reservoir attracts an inmigration of persons aware of the fishery potential, even though the indigenous populations may not be. These in-migrants will bring with them some appropriate fishing techniques and will establish a rudimentary fish processing, distribution, and marketing infrastructure. The eventual annual catch will depend to a large extent on the efficiency of this fishery infrastructure. Spontaneous, unregulated, and unserviced development of the fishery will result in overfishing, waste, inferior products and, in general, economic loss.

Our estimates also are of potential long-term annual catch. A reservoir fishery takes about ten years to stabilize and establish a plateau of productivity. This plateau may be exceeded during the early years of a reservoir because its

Table 5.2. Estimates of Annual Fish Catch Potential for Gambia River System Reservoirs

Reservoir	Maximum Catch Potential Total Tons/Yr
Balingho	5600
Kekreti	1400
Kouya	265
Kankakouré	34
Kogou Foulbe	177
Total	7476
Value*	$7,476,000

Catch potential based on application of adjusted morphoedaphic indices and moderate management inputs. Actual catch will require effective fishery management, especially the development of effective distribution and marketing systems.

*Value @ US$1/kg. This value varies throughout the Basin. It is about $1/kg in Senegal, but somewhat less in Banjul. Estimates are that $1/kg is a reasonable value to assume for the Balingho Lake fishery because of the demand in Senegal and The Gambia that will accommodate the supply. The considerable increase in supply at Kekreti Lake, however, may depress the price because of a limited local market.

University of Michigan Gambia River Basin Studies, 1985.

productivity will surge with the initial flooding of land and vegetation. Subsequently, the standing crop of fish, and therefore the catch, will stabilize at lower levels. As the standing crop of fish will depend on species composition, the introduction of a pelagic fish may be desirable in Lake Kekreti to take advantage of the offshore food supplies in the water column. Thus, the long-term production could be enhanced by careful management of the fishery.

This potential for the most part would be a net benefit if it could be realized. The current production of the river, based on models of African river fisheries, might be about 4,800 metric tons. However, our studies indicate that much of this catch is in the lower estuary, which will be extended, so considerably less than the 4,800 tons will actually be lost by the transformation of riverine environments to lacustrine environments.

The net benefit of the reservoir fishery could come at some cost, however, as the distribution of the fishery benefits will change. The reduction of fishery productivity in the remaining riverine sections will be at the expense of any flood-recession fishing that currently exists (in drought years this is minimal, as it varies according to the extent of annual flooding). In an average year, each km^2 of floodwater eliminated by Kekreti Dam might eliminate perhaps 1 ton of fishery production. Thus, artisanal and subsistence fishing could suffer in those areas, and its nutritional value for the local populations would be diminished.

5.3.2. Impact of Balingho Dam on Current Gambian Fisheries

The impacts of Balingho, especially downstream of the dam, are so uncertain in regards to the fisheries that we cannot analyze the costs and benefits. In our opinion, given optimistic assumptions, the catch potential of the Balingho reservoir might offset the losses to the catch potential of the existing fisheries. We estimate the maximum catch potential of the Balingho reservoir fishery to be 5,600 tons annually, for a gross value of $5,600,000. The net value of this fishery would be about $3,500,000, allowing for management and production costs. Whether or not the reservoir fishery will offset the losses to the marine, shellfish, and estuarine fisheries is a question requiring further investigation. The annual losses to the existing fisheries could range upwards of $1,400,000. The potential losses could be considerably higher, as the potential yield of these existing fisheries is assumed to be considerably higher than the present catch.

Fishery production in the Gambia varies considerably from year to year, and the ranges are quite extreme (Table 5.3.). From 1978 to 1982, for example, the

Table 5.3 Estimated Fishery Catch in The Gambia

	Catch (Metric Tons)	
	Commercial	Artisanal
Marine Finfish	7,400-20,000[1]	6,200 - 11,000[1]
Shrimp		227-412[2]
Oysters		150
Estuarine Fish		600-2,400[3]
Riverine Fish		630[3]

1. 1978-1982
2. 1982/83 and 1983/84, under contract to NPE (commercial)
3. 1982/83 and 1980

University of Michigan Gambia River Basin Studies, 1985.

catch from 6,200 to 11,000 tons. Commercial processing of shrimp was 227 tons in 1982/83 and 412 tons in 1983/84. The estuarine catch by artisanal fishermen was 600 tons in 1982/83, but 2,400 tons in 1980.

The information necessary to predict sustainable yields of these fisheries does not exist, although indications are that the marine and shellfish potential is considerably underexploited. The decline in marine catch seems the result of a decrease in fishing effort, perhaps due to increased fishing costs but also due to distribution and marketing constraints, rather than due to environmental factors. The evidence suggests that the marine fisheries could support considerable increases in fishing effort and harvest. Stocks of shrimp, lobsters, oysters, yeat, and crabs seem capable of sustaining increased levels of harvest. Only the estuarine fishery seems exploited sufficiently.

In this context, then, of wide variation in annual catch and underexploited potential, we can only identify possible negative impacts of Balingho on the fishery potential and suggest possible trade-offs with the potential of the reservoir fishery. If the net impact of Balingho is marginally or even somewhat negative, more effective exploitation of the remaining marine and estuarine potential could offset that loss.

Balingho will cause losses to the freshwater fishery above the dam, to the shellfish fishery above and below the dam, to the estuarine fishery, and to the marine fishery. The total loss could be $1,400,000 (Table 5.4.). More than 50% of the loss ($750,000) will be due to the impact of Balingho on the shellfish fishery. Most of the remaining loss will be of the freshwater fishery above the dam and from the marine fishery.

The losses to these fisheries will be due to various impacts of the dam. Upstream it will eliminate the shellfish habitat in the mangroves. It furthermore will eliminate migration of fish and shellfish from the estuary to brackish water, which will affect some commercial species. Most important, perhaps, it will block the flow of nutrients downstream to the remaining estuary and the coastal waters. In addition, the change of salinity will affect the mangroves downstream, and the loss of a salinity gradient could have an additional impact on shrimp productivity. Although the marine habitat will be expanded, the potential for pollution will pose a threat to fishery productivity.

The major loss of shellfish productivity will primarily be below Balingho, despite the loss of habitat above Balingho. About 10% of the current annual harvest

Table 5.4. Estimated Value of Catch Losses Due to Balingho Dam

	% Catch Lost	Value*
Shellfish Above and Below Dam	50%	$750,000.
Marine Coastal Finfish	10%	300,000.
Freshwater Fish Above Balingho**	100%	250,000.
Estuarine Fish Below Balingho	30%	100,000.
Total Loss		$1,400,000.

* Assumes 4 dalasis/US$1.
** To Kuntaur

University of Michigan Gambia River Basin Studies, 1985.

of shellfish ($1,500,000), most of which is shrimp, is above the Balingho site. The impacts on the estuary below the dam, however, could easily cause the loss of another 40% of the shrimp as well as oyster, crab, and lobster harvest. In sum, the potential reduction in shellfish stocks and production could easily exceed 50% of the current annual total.

Additional losses will occur to the marine and estuarine fisheries because certain species, such as the bonga and some catfish, either require or prefer brackish water during some stage of their life cycle. In fact, about 60% of the 1981 marine coastal fishery catch was composed of species that also inhabit the lower and upper estuaries at all stages in their life history. The extent of the dependency of these species on estuarine conditions is not fully understood, so the extent of the loss of fishery production cannot be predicted. We estimate less than a 10% loss to the marine coastal fishery and a 30% loss to the estuarine fishery. (The estuarine fishery in one sense will cease to exist, of course, as the species composition will change, but fishing will continue in these waters.)

Our conclusion is that a loss of an annual fishery production worth $1,400,000 due to the dam at Balingho is a reasonable estimate. The potential loss could be considerably higher. This is a cost to be considered against the possible benefit of the fishery that will develop on Balingho Lake, potentially worth some $5,600,000 in gross catch value if effectively managed. In actuality, the worth will be somewhat less because management, marketing, and distribution will not be as effective as would be required to reach this potential. The environmental impacts of Balingho are so uncertain, however, that further investigation is needed to determine whether or not Balingho Dam will have a net positive or negative effect on Gambian fisheries.

5.3.3. Net Annual Value of Lake Kekreti and Guinea Lake Fisheries

Based on the estimates of maximum annual fish catch potential for Lake Kekreti and the Guinea lakes (Table 5.2.), the potential value of the reservoir fisheries can be calculated. After 10 years, the fishery on Lake Kekreti could have an annual catch with a net value of $881,000 and the fisheries on the Guinea lakes a catch with a value of $274,000 (Table 5.5.). (These values are based on a retail price of $1/kg. In 1984, this also was the approximate price of fresh fish in the Kédougou market, although in Banjul the price was somewhat lower. The demand for fish from Lake Balingho is expected to increase the price of fresh fish from there, but the

Table 5.5 Benefit/Cost of Kekreti and Guinea Reservoir Fisheries

	Kekreti		Guinea	
Year	Potential Catch	Net Value	Potential Catch	Net Value
1	0	0	0	0
2	$140,000	$88,000	$44,000	$25,000
3	280,000	176,000	92,000	52,000
4	420,000	264,000	140,000	80,000
5	560,000	353,000	188,000	108,000
6	700,000	444,000	236,000	135,000
7	840,000	529,000	284,000	163,000
8	980,000	617,000	332,000	191,000
9	1,120,000	705,000	380,000	218,000
10	1,260,000	793,000	478,000	246,000
11	1,400,000	881,000	476,000	274,000
n	$1,400,000	$881,000	$476,000	$274,000

Assumptions:

1. Reservoir fishery reaches full potential ten years after reservoir fills. Analysis assumes liner development, although in actuality fishery will peak before the eleventh year and level off at a lower sustained annual catch.
2. Retail price of all fish is US$1000/metric ton.
3. Management cost for development of potential and estimated loss of existing fish stock is estimated at 25% of value of potential catch.
4. Fishery will sustain one canoe/km^2, with 75% of canoes without motor and 25% with motor.
5. Production costs include cost of canoe, fishing gear, outboard motor, fuel, oil, and maintenance:
   annual cost of canoe without motor = $45/year
   annual cost of canoe with motor = $1960/year

University of Michigan Gambia River Basin Studies, 1985.

demand for fish from Lake Kekreti and the Guinea lakes might not be sufficient to accommodate the supply. Thus, these estimated values may be optimistic.)

These values are based on stabilized catches of the fisheries after ten years of 1,400 tons for Lake Kekreti and a total of 476 tons for the Guinea lakes, with management and production costs estimated for the fisheries. To reach this potential will require moderate and effective management inputs, which we estimate to cost about 25% of the value of the potential catch. These fisheries also will have approximately one canoe/km^2, and perhaps 25% of them will have an outboard motor. Production costs, therefore, have to be estimated for the costs of canoes, fishing gear, outboard motors, fuel, oil, and maintenance. Given current values, the annual production cost for fishing with a canoe without a motor can be estimated at $45/year and for a canoe with a motor at $1,960/year. These fisheries also will require effective distribution and marketing systems, which currently do not exist in these areas.

5.3.4. Aquaculture Potential

A final impact of development actions will be the creation of the potential for aquaculture in some areas of the basin. The residual riverine stretches, the remaining estuary, and the new man-made lakes will all have sound aquaculture potential. Cage culture can be practiced in the lakes as well as in the river with its controlled flow. Pond culture can be practiced in the estuarine region and at the end of the bolons, where natural drainages may be blocked when the annual flood is eliminated. Rice paddy fish culture can be practiced throughout the extensive irrigation system that is proposed. In tropical river basins, as in Southeast Asia, aquaculture can become an important fishery production system. The Gambia River Basin, especially in The Gambia, is no exception.

6. URBAN AND REGIONAL PLANNING

Integrated river basin development implies national, regional, and urban planning even though this often occurs without explicit design. Implicit in primary and secondary development projects are a series of actions and interventions that will change the socioeconomic and sociocultural structures in human systems throughout the basin. Although our studies may not have addressed many of these directly, to the extent that it did a picture began to emerge of social changes far beyond those circumscribed within the boundaries of specific development projects. The management concern should be that these changes are integrated and harmonious rather than fragmented and dissonant.

In African River Basins Thayer Scudder calls these changes the multiplier effects of river basin development. Most of the management actions that he identifies as appropriate for integrating these changes are introduced in our various team reports. We have introduced agricultural diversification and the relationships between national economic policies and rural agricultural economies; the various infrastructures needed to link and support complementary development projects such as construction of dams and expansion of irrigation agriculture; reorganization and creation of interrelated village and urban communities; and management structures from the national to regional and local levels.

Specifically, development actions will impact on various socioeconomic infrastructures, sociocultural institutions, and public health (Figure 6.1.). We have been concerned with the urban and village planning required for construction of dams and resettlement of persons displaced by the reservoirs; the impacts of development projects on the migration patterns in the basin; the implications of agricultural development for marketing and pricing structures; the planned and required transportation networks; the development of local industries; management and extension infrastructures; community and public health services; and land and water use patterns. Even though the discussion of these often had to be qualitative in terms of impacts and economic implications, it is important that these be introduced as management actions and interventions that will modify the basin ecosystem as substantially as the more immediate and observable actions.

The construction of dams, the creation of reservoirs, the development of agriculture, the improvement of transportation systems, and the generation of hydroelectric power undoubtedly will lead to the development of commercial towns

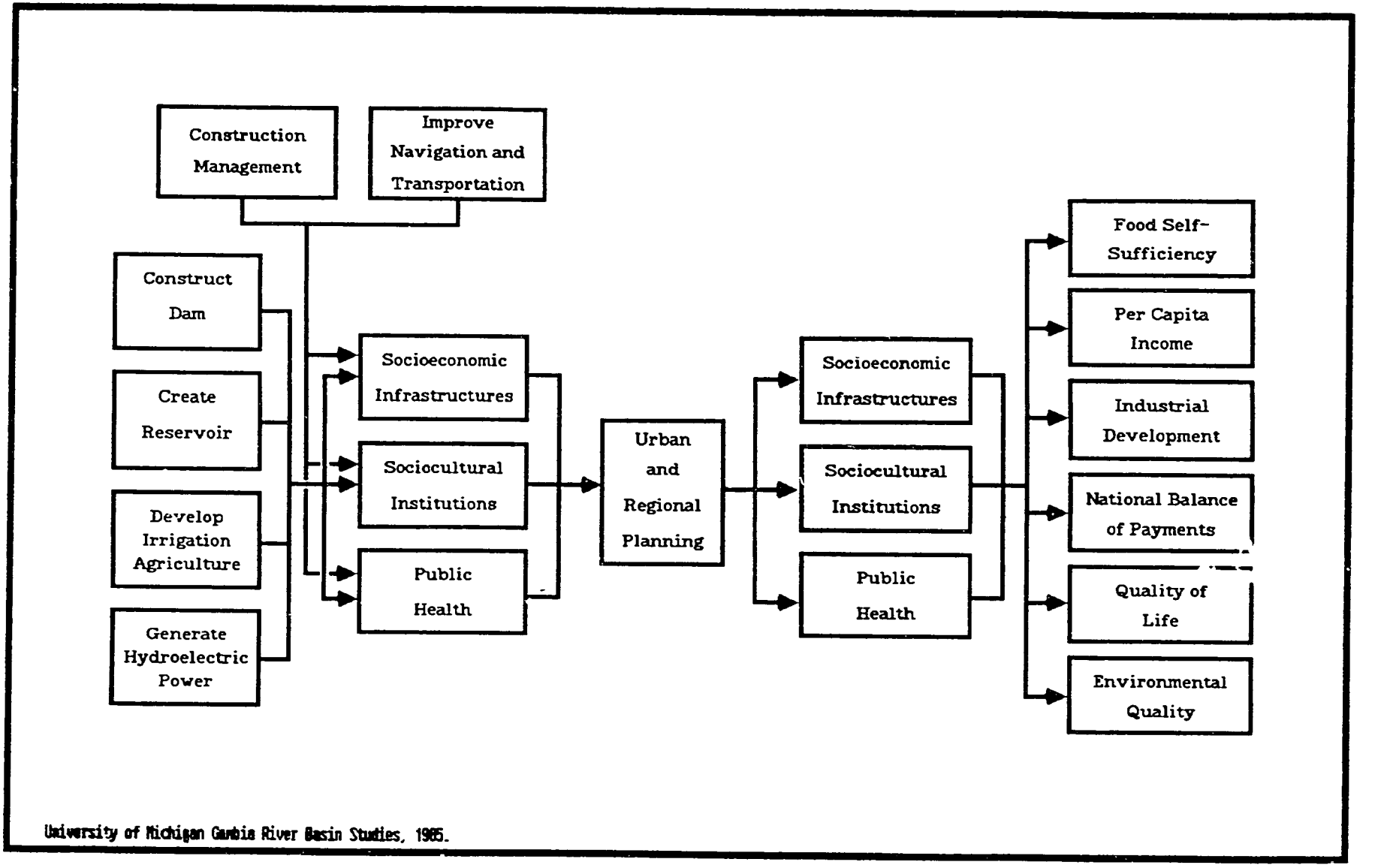


Figure 6.1. Urban and Regional Planning Network

that will be regional hubs for these various production and economic projects and their supporting infrastructures, especially if effective management actions are taken. A plausible scenario would be for a construction village to develop into a town or even a regional center, especially being located on such a magnet as a lake of year-round fresh water. The intensive development of 70,000 ha of irrigated agriculture also could lead to the development of such foci of marketing, distribution, service, and communication activities. Effective urban and regional planning will be required for the changes in socioeconomic infrastructures, sociocultural institutions, and public health to contribute to rather than inhibit the achievement of development objectives. In addition to the economic implications of these impacts, the quality of life of the basin populations should be of primary concern.

6.1. Urban and Regional Planning Impacts

The development projects will require numerous trade-offs among various socioeconomic and sociocultural institutions in order to enhance economic productivity in the basin (Figure 6.2.). The result of the projects and consequent effects on population patterns in general should be to enhance transportation and communication systems, improve marketing and distribution systems, foster the development of light industry, and establish administrative infrastructures heretofore relatively nonexistent. These impacts are almost assumed -- and require effective planning, of course -- if the various development objectives are to be achieved, as discussed in Chapters 4 and 5 as well as, in part, in this chapter.

A systematic view would require detailed analyses of the ultimate impacts of these various developments on community services, social organization, cultural patterns, and even compound organizations throughout the basin. Although such analyses are beyond the scope of this project, a summary of some of the intermediate impacts suggests that to various extents many of these sociocultural attributes will be negatively affected, especially in the short term.

Given appropriate management precautions, community services as a whole could be improved by development actions although locally they may be disrupted. Social organization, however, such as authority structures, will be placed under extreme stress by the impacts of resettlement, intensive irrigation agriculture, and other activities. Cultural patterns, especially ethnic relationships, will suffer as

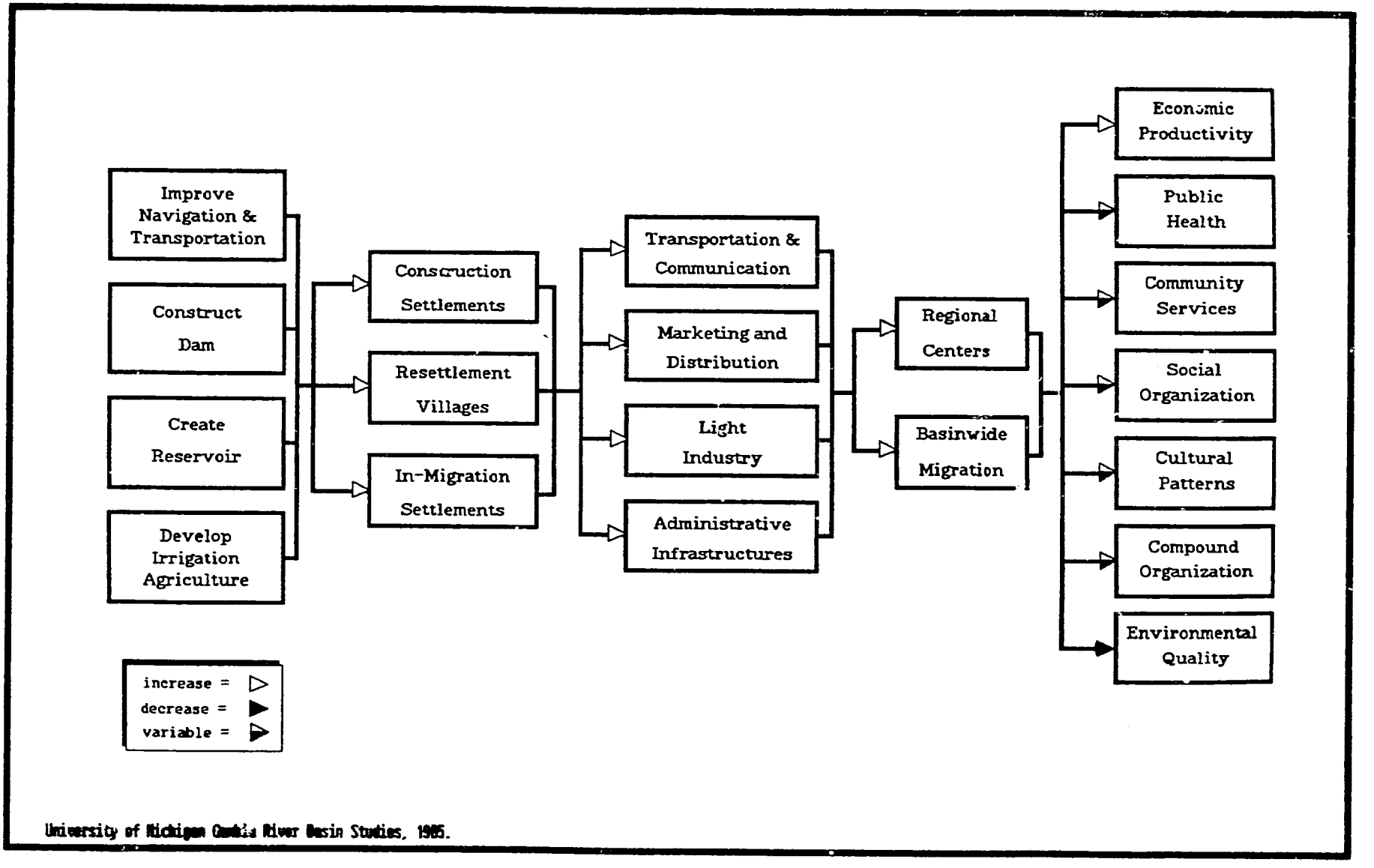


Figure 6.2. Socioeconomic and Sociocultural Tradeoffs of Basinwide Development

populations are displaced and various population movements accelerated. Compound organization almost certainly will be affected by the flooding of swamp rice fields, irrigation agriculture, and new employment activities.

Impacts on public health will be negative in so far as incidence of disease goes. The long-term impacts on public health, however, could be positive for some important attributes.

6.1.1. Impact Attributes

The impacts of urban and regional planning for the most part can be described in terms of attributes drawn from environmental impact methodologies, although we have supplemented those with several additional attributes pertinent to the Gambia River Basin (Table 6.1.). Our studies focus on settlement patterns and the formation of villages, towns and, perhaps, regional centers. These are interrelated with various socioeconomic infrastructure attributes, such as marketing systems, transportation systems, and employment opportunities.

Important sociocultural attributes include compound organization and division of labor, especially in regard to the role of women. Ethnicity, or the role of minorities, is an important attribute in regards to projects in Senegal Oriental and Guinea. In-migration and out-migration will be of concern throughout the basin.

With regards to public health, the most important attributes are those of water-associated diseases, especially schistosomiasis, malaria, and onchocerciasis. Equally important in terms of development objectives is nutrition. Diet and nutrition, domestic sanitation, and drinking water are other attributes that define the impacts of development projects on public health.

6.1.2. Summary of Impacts on Settlements

- Construction settlements. Four construction settlements, each at least 2,000 persons and with platforms of 200 ha, will be required.
- Balingho town. The Balingho construction settlement will become an important economic and transportation center.
- Kekreti town. The Kekreti construction settlement could become a regional hub as the lake fishery and other activities develop.
- Resettlement from Lake Balingho. Although Lake Balingho will not displace people physically -- assuming Kuntaur is not inundated -- up to 15,000 persons may need resettlement because the lowland rice fields of numerous villages will be lost.

Table 6.1. Urban and Regional Planning Attributes

Terrestrial Biosphere

Villages
Towns
Regional Centers

Socioeconomic Infrastructure

Marketing Systems
Distribution Systems
Banking/Credit
Communication Systems
Roads
Navigation
Employment Opportunities
Entreprenurial Opportunities
Labor Availability
Administrative Infrastructures

Public Health

Mortality
Morbidity
Water-Associated Diseases
- Schistosomiasis
- Malaria
- Onchocerciasis
- Other

Other Diseases
Nutrition
Diet
Drinking Water
Domestic Sanitation
Water Safety
Livestock Diseases
Health Delivery Systems
Health Costs

Sociocultural Institutions

Settlement Areas
Settlement Patterns
Population Distribution
Population Density
In-Migration
Out-Migration
Community Services
Waste Disposal
Water Supply
Utilities
Electrification
Land Tenure
Ethnicity
Education/Schools
Division of Labor
Authority Patterns
Compound Organization
Social Organizations
Cultural Patterns
Quality of Life
Environmental Quality

Socioeconomic Production

Resettlement Costs
Agriculture Production
Fishery Production
Light Industry Production
Domestic Industry Production
Employment
Crafts and Artisanship

University of Michigan Gambia River Basin Studies, 1985.

- Resettlement from Lake Kekreti. Lake Kekreti will force the resettlement of 8,000 to 18,000 persons.
- Resettlement in Guinea. Lake Kouya and Lake Kankakoure will force the resettlement of some 1,000 persons.
- Inundation by Lake Kekreti. Lake Kekreti will inundate part of Salemata and disrupt administrative structures in the arrondissement.
- In-migration. The construction activities and formation of the manmade lakes will create a spontaneous in-migration of persons from other regions and countries.
- Fishery villages. Exploitation of the potential reservoir fisheries will provide a livelihood for a minimum of 7,000 persons (fishermen and families) around Lake Balingho; 3,400 at Lake Kekreti; and 1,500 at the Guinea lakes.

6.1.3. Impacts on Socioeconomic Infrastructures

- Transportation systems. Development projects will directly and indirectly improve transportation systems in the basin.
- Roads. Heavy duty all-weather roads will be required to serve dam construction sites. Perhaps 300 km of new and improved roads will be required just in the vicinities of the sites.
- Navigation. A year-round water transportation system will extend 800 km from Banjul to the upstream boundary of Lake Kekreti.
- Marketing at Balingho. Commercialization will be intensified by the dam at Balingho.
- Marketing in the Kekreti region. Regional marketing patterns will be disrupted by the Kekreti project.

6.1.4. Sociocultural Impacts

- Impacts on women. The loss of swamp rice to Lake Balingho, the elimination of tidal rice, and loss of rice land to irrigation development will mean that women will lose a major productive role.
- Impacts on men. Construction employment will attract men, with uncertain implications for household nutrition. Many men may not return to agriculture.
- Impacts on minorities. Construction of dams at Kekreti and in Guinea will exacerbate the interethnic tensions in those regions. It could place the Bassari, Bedik, Malinke, and Diallonke social fabrics at risk.
- Hiring and minorities. Hiring at construction sites could generate considerable ethnic tension.

- In-migration. In-migration will be accelerated around Lake Kekreti.
- Out-migration from the Kekreti area. Resettlement at Kekreti will stimulate some outmigration as well.
- Out-migration from the Lake Balingho region. Lake Balingho probably will stimulate extensive outmigration of whole families and possibly whole communities. The Serekunda/Brikama region would receive most of the migrant population.

6.1.5. Summary of Impacts on Public Health

- The Gambia. Urinary schistosomiasis will become much more prevalent. Intestinal schistosomiasis, now hardly existent, will be established. The incidence of malaria will increase.
- Senegal. Urinary and intestinal schistosomiasis will become prevalent and perennial. The incidence of malaria will increase. The incidence of onchocerciasis will be slightly reduced.
- Guinea. The incidences of diseases will not be affected to a significant extent. Some schistosomiasis will spread in association with irrigation from Kogou Foulbe. The incidence of malaria will increase somewhat. The incidence of onchocerciasis will be unaffected.
- Other diseases. Impacts of development projects on other diseases will require monitoring, but will not be of continuing concern.
- Urbanization. Urbanization will increase the transmission of diseases among humans in the short run.
- Resettlement. Resettlement inevitably entails negative health consequences.
- Construction. Construction activities and settlements will increase the incidences of many diseases.
- Community services. Improved water supply, sanitation, and health care services have the potential for considerably improving public health in the long run.
- Nutrition. As irrigation agriculture projects are implemented and fisheries develop, the nutritional status of the populations should improve.
- Economic implications. Public health costs might reasonably be charged against development projects.
- One-time costs. Balingho will incur one-time costs of $114,000; Kekreti $234,000; and the Guinea dams at least $77,000.
- Annual costs. Balingho will incur annual costs of $157,000; Kekreti $136,000; and the Guinea dams at least $69,000.

- Irrigation costs. Each 5,000 ha of irrigation agriculture will incur annual costs of $20,000 for schistosomiasis control.

6.2. Impacts on Settlements

The development activities will have a significant impact on the population distribution and settlement patterns in the Gambia River Basin. Certain regions in the vicinity of the primary development activities will be almost transformed insofar as the human presence in the environment is concerned. The redistribution of the basin populations will be initiated at the village level with construction settlements for the dams, the resettlement of populations dislocated by the reservoirs, and the settlement of people attracted by the reservoirs. As intensive agriculture is phased in, additional settlements will be required for the labor forces and their families. The redistribution of populations will continue at the regional level as administrative and commercial centers develop to sustain these relocated populations and support the various economic projects -- agricultural, fishery, industrial, and service. Throughout the development period the dynamics of population shifts basinwide and beyond will be modified.

6.2.1. Construction Settlements

The five dams will require at least four construction settlements, each of at least 2,000 persons and 200 ha. These numbers may be extremely conservative, as they are based primarily on numbers of workers and dependents. Quite possibly, as Thayer Scudder suggests, these numbers might double with the influx of "job seekers and others coming to provide a wide range of goods and services" (1985).

In terms of size as well as function, these will become towns in the short run. The geographic location of each will determine whether or not they will remain viable towns or even develop into regional centers. A reasonable assumption would be for Balingho town to become a regional center -- or a second hub in tandem with Farafenni -- almost immediately. Kekreti town seems likely to evolve into a town of some importance, despite the proximity of Kédougou, because Lake Kekreti will be a regional magnet for people and productive activities. The long term development of the construction towns in Guinea is less certain.

Each construction village will require considerable advance planning as well as ongoing administration. A construction settlement will have about 200 professionals and skilled workers, 1,000 semiskilled workers and laborers, perhaps up to a 1,000

dependents, numerous job-seekers and others providing various services and goods, and a number of administrators and public officials. If these villages are similar to those elsewhere in Africa, each will have a rather well laid-out platform with treated domestic water supply, professional staff residences, worker housing, supermarket, open market, hospital, church or mosque, school, fire station, electrification, recreation fields, community facilities, garbage disposal and community equipment center, and sewage treatment systems. The construction village undoubtedly will be more developed than many surrounding villages, and for that reason alone become the focus of regional attention. Only at the Balingho site might provisions not have to be made initially for a self-contained construction village, as the work force could be distributed among the various villages in the rather densely populated surrounding area.

The construction villages will be viable towns because of their critical economic mass. Construction of dams is both labor intensive and material intensive. The impact of such a project at both local and regional levels will be far beyond the experience -- and even comprehension -- of the populations involved. The economic explosion will require an extensive administrative infrastructure as well as attract hundreds of persons from near and far. The local labor market will not be able to supply the demand for skilled and semiskilled labor, or even perhaps for all of the manual labor. The recruitment of these from elsewhere will be supplemented by the voluntary in-migration of others, as well as entrepreneurs for service and cottage industries, trade persons, farmers and livestock producers, fishermen and fish processors, and transporters. The impact will be long-enduring, as the construction project will last six or so years. For a number of years the village will be a hive of intense economic activity and thereby hold promise for future development.

The logistics of the project also will require that the villages be viable towns. The materials and equipment required for dam construction will require an extensive communication system to be developed, with a complex of service roads linked to basinwide transportation systems. The town will be the administrative center for this continuous flow of traffic, people, and materials. In recent years, for example, estimates indicate that, on the average, 300 vehicles cross the Gambia River at Yelitenda daily. Some estimates for the dam at Balingho are that for a year and one-half more than twice that many trucks would arrive daily with fill and aggregate.

The potential for the construction villages to become regional centers depends on, whether or not the dams and reservoirs will become or will be planned to become administrative and economic centers. It is difficult to envision how Balingho town will not become an important economic center. The dam not only will serve as a bridge across the river for the Trans-Gambian highway; it will have locks for ocean-going transport. If water transportation is developed as envisaged, perhaps up to Kekreti Dam and to the end of Lake Kekreti, Balingho town will become even more important. Thus, Balingho town will be a port that will link ocean transport to land transport, even if Banjul continues to be the primary ocean port for The Gambia. As a centrally located port facility, Balingho and the surrounding area will become an important transportation center -- warehouses, storage yards, truck depots, maintenance facilities, customs and shipping offices, etc.

The fate of Kekreti village will depend on urban and regional planning policy. After the dam is completed, the population nucleus will be reduced essentially to operation and maintenance personnel for the dam and hydroelectric power generation. Most of the labor force will depart. The function of Kekreti village in the economy of the dam construction and as the site for hydroelectric power generation will establish it as a town during the construction, reservoir filling, and start-up period. Its long-term potential, however, will be derived from its location on the shore of a vast lake that will attract hundreds of persons and initiate various commercial activities such as a fishery and perhaps fishery industries. A reasonable assumption is that Kekreti town would become the hub for regional service processing, storing, and marketing industries in support of the fishery, agricultural, and livestock production in the vicinity. A network of primary and secondary roads will have been established for dam construction, which subsequently will be complimented by the water transportation system that evolves.

In addition, Lake Kekreti will serve as a gateway to Niokolo-Koba National Park. This tourist potential will complement the recreational potential of the lake itself. A positive asset for such a tourist industry could be the small hospital and dispensary the construction contractor will leave behind. Thus, the Kekreti region will become a development region, with all of the requirements for administrative, economic, educational, and public health infrastructures. Whether or not Kekreti town becomes a second regional center complementing Salemata and Kédougou will be a function of regional planning policy.

6.2.2. Resettlement Villages

Resettlement policy will be an important and necessary component of urban and regional planning. Some thousands of persons will be displaced by the reservoirs, although in terms of actual numbers the problem will not be as severe as it has been elsewhere in Africa. The situation will nonetheless be significant for those involved. It will be significant for the achievement of development objectives as well.

The impacts of resettlement involve more than the uprooting of persons from their homes, villages, and lands. The issue is more than one of trying to resettle persons in situations approximating those to which they are accustomed. Development activities are dynamic, designed to improve the economic status and quality of life of populations basinwide. Those populations directly impacted by the construction of dams and creation of reservoirs, however -- those that have to be resettled -- in general are those who will benefit least from the development projects. In the case of Kekreti, which will displace most of the persons to be resettled in the basin, the populations affected will lose prime agricultural land without adequate compensation in order that thousands of hectares of irrigation projects far downstream can be developed.

The impacts of the reservoirs will be quite different. Balingho reservoir will not displace people physically, assuming that Kuntaur is not partly inundated. For this reason, the RRI report assumes no resettlement will be required by the Balingho project. Thus, while a probability limit, seems improbable. Lake Balingho will flood the lowland ricelands of numerous villages, lands that cannot easily be replaced. The population to be affected could approximate 75,000. Because of this, we estimate that up to 15,000 persons may need resettlement. To fail to consider the probability of resettlement could lead to serious negative impacts on the affected populations.

We therefore conclude that some resettlement compensation will be incurred by the Balingho project when land use and tenure are determined; resettlement or migration undoubtedly will result due to the lack of sufficient agricultural uplands to support the populations displaced from their traditional rice fields. This problem is more severe when cattle grazing land is considered. Currently, there is from 0.5 to 1 animal per person in the impact area. Thus, considerable grazing land also will be flooded and therefore required elsewhere by the populations displaced.

Lake Kekreti will flood lands in the arrondissements of Bandafassi and Salemata, where the population density ranges from 6.5 to 7.6 persons/km^2 according to AHT. A minimum of 8,000 persons in 28 villages will be flooded out by the new reservoir or else have most of their agricultural land flooded out by the reservoir and be forced to move elsewhere. The number of persons needing resettlement by the time the reservoir actually fills, however, may reach 18,000. This seems more probable than the conservative estimate of 10,600 in the AHT/HHL report, considering realistic population growth projections, a later date for construction of Kekreti, the possibility of in-migration before the dam is built, and, especially, the number of persons to be resettled because some or most of their agricultural land will be inundated. (The World Bank now requires resettlement provisions for some households who lose cultivated land even though their village platforms are not inundated.)

These persons will lose prime agricultural land along the river and be displaced to areas with less agricultural potential. The assumed displaced population will need a minimum of from 6,500 to 13,500 ha of agricultural land, in addition to grazing land and land for village platforms. If the upper estimate of persons needing resettlement is approached, as much as 30,000 or 40,000 ha of land will be required.

In Guinea, Kouya and Kankakoure will force the relocation of some 1,000 persons. Kogou Foulbe, in a sparsely populated region, probably will not require resettlement contingencies.

The implications for resettlement in the Kekreti region are somewhat complex. The dam and reservoir will significantly modify the societal structures in the region. It will mean a considerable loss of population and production, particularly in the arrondissement of Salemata. The reservoir also will physically separate the people in the arrondissement. Diakete will not be able to serve as the center of its current communauté rurale, and in any case will no longer be of sufficient size to do so. Salemata, with its school, dispensary, mission, store, and offices, will be partly inundated and therefore will need to be partially rebuilt. The trade and market network of the arrondissement will be disrupted and require reestablishment.

For the populations concerned, the issues of resettlement involve far more than the questions of land management. They involve numerous socioeconomic infrastructures and sociocultural institutions that form the very fabric of their quality of life. Resettlement will affect the populations remaining in the region of departure, the populations being relocated, and the populations in the region of

relocation. The issues involve ethnic distribution, authority structures, land tenure, choice of crop mix and subsistence diet, division of labor, marketing systems, communication systems, education, public health, water supply and sanitation, and administration.

6.2.3. In-Migration Settlement

Planning should anticipate the spontaneous in-migration of persons to the dam and reservoir development areas. The economic opportunities provided by the construction activity and the economic and environmental attraction of the reservoirs will attract persons from elsewhere in the basin as well as from outside. Those attracted by the construction activities will contribute to the growth of the construction towns. Those attracted by the manmade lakes, however, will establish new towns. It might be reasonable to assume that basinwide the in-migration phenomenon ultimately will involve more persons than will be resettled.

When a reservoir creates an abundantly available and stable water supply with its abundant supply of fish, people are attracted from near and far. For the most part, this lake population will not be drawn from the indigenous populations in the region. The core of the new population will be the fishermen and their families who will establish new fishing communities to take advantage of the new reservoir fisheries. They will be supplemented by those who will come to provide the ancillary services and to take advantage of resources of the lake for agriculture, industry, navigation, recreation, and tourism.

If, for example, the potential reservoir fisheries are fully developed, up to 7,000 persons (fishermen and families) will settle around Lake Balingho, 3,400 around Lake Kekreti, and 1,500 around the Guinea lakes (Table 6.2.). To these persons would be added those necessary to support the fishery infrastructures, such as motor maintenance, transportation of fuel and goods, fish processing and marketing, etc. Such a scenario, of course, assumes improvement of existing marketing, transportation, and agricultural systems. The production of the fisheries would far exceed the local demand, while the agricultural needs (e.g., rice) of these populations probably would exceed local rainfed production. This is an example of the coordinated urban and regional planning necessary to meet development goals — here those of the fisheries -- assumed in benefit/cost analyses.

For urban and regional planning purposes, therefore, these new towns must be considered separately from the construction villages. The construction villages will be located in proximity to the dams themselves. As these develop into ports and

Table 6.2. Minimum Populations Necessary to Exploit Fishery Potential

Balingho	7000 persons
Kekreti	4000 persons
Guinea Dams	1500 persons

Assumes 2.5 men/canoe, each with an average of 4 persons/family. Does not include persons supporting fishery infrastructures -- motor maintenance, marketing, etc.

University of Michigan Gambia River Basin Studies, 1985.

Table 6.3. Perimeters of the New Manmade Lakes

Balingho	508 km^2
Kekreti	572 km^2
Kouya	200 km^2
Kankakouré	41 km^2
Kogou-Foulbe	120 km^2
Total	1441 km^2

University of Michigan Gambia River Basin Studies, 1985.

transportation centers, of course, they will attract some of the migrants. At the same time, the new lakes will have hundreds of kilometers of shoreline (Table 6.3.). A gross estimate is about 1,440 km^2, but the actual irregularities of the shorelines will significantly increase this amount. Thus, planning for settlement and the development of new villages and towns should take into consideration the entire perimeters of the lakes. These additional lakeside villages will exploit the forests and natural vegetation, raise crops and livestock, and require the public, community, and public health services provided for the construction and resettlement villages.

In addition, the remaining riverine stretches of the river will attract people with livestock because of the year-round supply of fresh water and regulated flow that will eliminate annual flooding. If the experience on the Gambia River parallels that of other regulated African rivers, this increase in riparian population will far exceed that expected from normal population growth. Although some of these persons will spread along the banks in family compounds, some presumably will form rural villages. Several of these villages may develop in association with the irrigation agriculture settlements that may form.

Finally, as irrigated agriculture is developed on the scale projected by the development scenarios, urban and regional planning might provide for temporary in-migration for the labor required for the irrigation perimeters. Most development models are capital intensive because of the scarcity of labor necessary to develop irrigation agriculture on the scale envisioned. In addition, the return to labor assumed in these models probably is insufficient to attract the labor force for labor intensive development (LRDC provides 1.9 dalasis/day, which is a marginal daily rate for women and less than half the daily rate for men). Despite these considerations, significant expansion of irrigation agriculture in sparsely populated areas such as Bansang Nibras, the North Bank MacCarthy Island Division, and Senegal Oriental might require that provisions be made for importing labor for certain periods of the year.

6.3. Impacts on Socioeconomic Infrastructures

Impacts on important socioeconomic infrastructures will need to be analyzed to complete a comprehensive overview of basinwide development, especially for economic evaluations of the long term effects of development projects. As irrigation agriculture is significantly expanded and fisheries become established, for these to be viable numerous food processing industries, for example, will have to

emerge. The potentially positive impact of development projects on transportation, therefore, might be suggestive of impacts in other socioeconomic areas -- if needs are anticipated and appropriate plans formulated. Marketing structures similarly will be affected, as briefly discussed in Chapter 4. Impacts on local markets, as discussed below, will be short term disruptions.

6.3.1. Transportation

The current state of transportation networks in many parts of the basin poses a serious barrier to efficient production and marketing systems. The construction of dams and development of irrigation projects will lead to important improvements in the roads, which should markedly improve various input and marketing processes.

Although communication by main road is reasonably good between centers of population in the lower part of the basin, the upstream half of the basin lacks all-season, all-weather roads. Apart from the relatively few satisfactory main roads that characterize the southern part of the basin in The Gambia and parts of Senegal Oriental, "self-maintaining" trails and tracks prevail. Communication between Kédougou and Tambacounda is inadequate for commercial purposes, and four-wheel drive vehicles have difficulty in many parts of Guinea. In the wet season many roads are impassible.

One of the primary problems in the basin, according to persons we talked to in rural areas, has to do with poor roads and difficulty of transport, particularly during the wet season. The lack and cost of transport are serious constraints to producer-level marketing of agricultural products. These are particularly important when long distances are involved. To avoid high costs, many farmers sell locally, most only within a few kilometers of their village. To transport a 100 kg sack of millet 10 km by horse cart in Senegal costs from 500 to 600 CFA, about one-seventh of the postharvest free market price.

The same problems plague the fisheries. Road networks in The Gambia are improving, but primarily to serve the groundnut industry. Roads from the main highway to the river usually are poor and deteriorate quickly during the rainy season. Fishermen say that marketing problems are the most serious impediment to expansion. Once perishable fish have been landed and cleaned, there are no efficient mechanisms to transport them to market. From major fish landings we have seen fresh fish transported in baskets ten or twenty kilometers by bicycle. Alternatively, the fish are processed by the wasteful sun-drying technique. In Senegal, marketing problems are more extreme and prevent any significant

transport of fish among villages, although marine fish are marketed in Tambacounda and Velingara because these towns are well served by the national road network.

The development projects directly and indirectly will improve transportation in the basin. Service roads to the dam sites and damsite villages will be all-weather paved or gravel roads. Additional access and service roads, such as for transmission lines, will be developed. Linkages of necessity will be established among the resettlement villages. From these and previously existing roads, unplanned access routes will evolve from points of human population pressure, such as new centers of in-migration along the lakes. Although the reservoirs will cut some important roads, such as between Kédougou and Salemata, at these points on the lakes settlements and trading centers will most likely arise and become minitransportation hubs linked with water transport. Additional service routes will be developed to service irrigation perimeters, many of which are proposed for areas not well endowed with year-round roads capable of serving as input and marketing conduits.

The requirements just for dam construction illustrate the impacts on transportation systems. Although the Balingho site is well served by the Trans-Gambian highway, 17 km of the highway will have to be rerouted. Additional all-weather gravel roads will be required to connect components of the project. At Kekreti, from 80 to 100 km of access roads will be built or upgraded, and the Kédougou-Salemata road will be upgraded and a new 46 km section added. Kouya and Kankakoure will require a minimum of 80 km of all-weather access roads, and Kogou Foulbe an undetermined amount. Given the scale of these construction projects, the transportation infrastructures serving them undoubtedly will be upgraded throughout the region.

The road networks will be complemented by a water transportation network. River transportation is envisioned from the mouth of the Gambia River to the upstream boundary of Lake Kekreti, over 800 km. Balingho Dam will have ship locks, and the river will be dredged to enable upstream transportation. Dependable river navigation and transportation will be an important benefit necessary to attain development objectives. Bulk transport of agricultural products and supplies, such as cereal grains, groundnuts, and fertilizer, and of solid and liquid fossil fuels is economically more efficient by river than by truck.

In general, the resulting land/water transportation network should greatly improve transportation throughout the basin. This will be essential to agricultural development and effective exploitation of the fisheries. The regions marked for

irrigated agriculture development in The Gambia and in Senegal Oriental will be directly served by the river transportation system. The regional road network supporting the Kekreti site should improve the marketing system. Any development in Guinea will provide a net transportation benefit.

6.3.2. Marketing

Development activities in general will improve marketing and communication in regional areas, although some marketing structures will be disrupted and will need to be redeveloped.

The proposed construction at Balingho will intensify commercial and urban tendencies, especially because of the expected influx of laborers and migrants. The area surrounding Farafenni and Jenoi, which includes the ferry and Trans-Gambian highway, is a major trade center in the basin. Current marketing patterns will be altered, intensifying the need for domestic products (particularly foodstuffs) in much larger quantities.

Current marketing patterns in the Department of Kédougou will be disrupted by the Kekreti project. Consequently, village specializations and crafts dependent on markets will be changed. These markets serve both Senegalese and Guinean villages, and people come by foot since roads are relatively poor and truck transport is limited. The numbers of construction workers and their demands will overwhelm existing structures. Agricultural production may decline as rural populations seek to gain more income in construction employment or in providing a range of services to the new centers. There will be a dual disruption: at the time of construction, and after the reservoir has filled and new roads and communication links are established. New weekly markets will need to be created.

Local marketing will not be much disturbed around Kogou Foulbe, but regional patterns will be altered by both Kekreti and Kogou Foulbe. In general, the sites in Guinea are in isolated sites. Most marketing relies primarily on head loading (foot traffic) for moving goods. Lacking vehicles and decent roads, people walk long distances to the nearest markets. Those living in Balaki, for example, must cross the Gambia River, which will be much more difficult when Lake Kouya is created. The same will be true along the Liti River, where movement across the river now is easy. What truck transport there is in Balaki depends on the sole vehicle bridge across the Gambia River, which will be flooded by the dam at Kouya.

6.4. Sociocultural Impacts

The sociocultural impacts of development projects of the scale envisioned for the Gambia River Basin will be pervasive, extending far beyond the scope of our studies. In addition to examining the implications of resettlement, however, we examined other features of the affected populations. In particular, we looked into the impacts on the role of women in these rural areas, on the various ethnic minorities in the development areas, and the implications for migration flows. In all three areas, the impacts will be problematic.

6.4.1. Impacts on Women

The roles of women in many household structures will be significantly affected by development actions. The loss of swamp rice to Balingho and the eventual loss of other rainfed rice will mean that women will lose a major productive role. Construction activities will also affect the women in many households.

The construction of the dam at Balingho will mean the loss of 15,000 ha of swamp and tidal rice, as discussed in Chapter 3. These lands are worked by women, and are an important source of household nutrition and income. Although work in swamp rice fields is arduous and time-consuming, women still are provided with a source of control over both production and consumption. The rice contributes to the overall nutrition of the households with access to its cultivation. The loss of these rice fields will diminish women's access to what has become a household staple and will alter household structures because women will lose a major productive role. With 15,000 ha, large numbers of women are involved and households will be deprived of a highly nutritious food. In addition, families already pressed to meet income and food needs will be put under extreme duress.

Irrigation development also will affect the role of women. As discussed in Chapter 3, the lands put under irrigation will include up to 43 percent of land currently in production. Most of this consists of women's rice fields. As rice is a more reliable crop than millet and sorghum, the loss of rice may not be mitigated where women have been more responsible than men in providing food for the household.

The loss of tidal and other rice lands will affect not only women. If all women who lose rice lands have rights to plots elsewhere, pressure on the uplands will force people, when possible, to go even farther to find fields. The entire village agrarian system will have to adjust to new conditions.

Dam construction will have an additional impact on family structures. Construction activities are likely to attract numbers of local men as wage laborers, with uncertain implications for agricultural production. Men who obtain employment may not necessarily purchase food to compensate for the loss of their agricultural productivity. They may spend their income in other ways, some of which will have deleterious consequences for household nutrition. Studies of other dam projects show that household income can go up while nutrition goes down.

6.4.2. Impacts on Minorities

Construction of dams at Kekreti and in Guinea will likely exacerbate the interethnic tensions in those regions. Over the years, migration into the Kédougou region has changed the geographic subdivision of the area into ethnic territories and has engendered tensions between the Fulbe and other groups. This mistrust is partially historic but is also due to the tendency of the Fulbe to take over the commercial circuits. It also is due to the increasing competition for land between livestock and agriculture.

The construction of Kekreti Dam and the accompanying shift in population and resources could place the Bassari, Bedik, Malinke, and Diallonke social fabrics at risk. The site at Kekreti is close to the heartland of the Bassari, who already are faced with internal and external pressures to change. In addition, there are explicit and latent interethnic tensions in the region. One characteristic of minority populations is their lack of access to resources and power, which will make it relatively more easy to resettle these affected populations than would otherwise be the case. At the same time, there is an obligation to recognize the uniqueness and fragility of these populations. The Diakhanke and Fulbe are less at risk and appear to be capable of adapting more easily to changing conditions.

The attraction of the construction activities will have significant effects on the regions. The hiring process itself will generate considerable ethnic tensions. The difficulties in ensuring equal access to job openings and balancing employment can be considerable. If a project hires large numbers of nonlocal workers, as it is bound to do, an extra dimension will be added to the problem.

The construction of Kogou Foulbe will affect the same peoples in Guinea because of the close ties maintained across the national borders. Younkounkoun is very near Salemata, and patients often are referred from Salemata to the hospital at Koundara. As in the Kédougou region, the smaller groups are removed from the political process in the prefecture of Koundara. Indeed, because the Bassari and

Cognagui are viewed negatively by many, special attention should be paid to how they will be affected by the dam.

Furthermore, almost all adult men stated that they would like to work on the construction crews, which would drain manpower from agriculture and upset settled patterns of life. Those who succeed in getting jobs will be out of agriculture for the duration of the projects and may never return. Even those who do not find construction work may leave agriculture in search of income elsewhere. Presumably, these projects will increase the rate at which young men are leaving their villages.

6.4.3. Impacts on Migration

A very important and long-term effect of all of the dams, but especially of Kekreti, will be on the movements of people. The effect will be noticeable almost immediately in the region around Kekreti. Both in-migration and out-migration movements will occur.

In-migration will be accelerated in local areas -- to the Balingho site as commercial activities expand there and especially to Lake Kekreti. Historically, the Kekreti area has been attractive due to the availability of water. This attraction will be intensified by the creation of Lake Kekreti. The lake also should draw large numbers of livestock, especially during the dry season. Given the limited availability of agricultural land after the lake is formed, employment opportunities will motivate migration far more than agriculture. Certainly, the fishery alone will attract many outsiders. These migrants will compete for employment and resources with the region's original inhabitants. Interethnic tensions will likely be intensified.

The long-term trends of rapid population growth and accelerating urbanization should be expected to continue, regardless of the impacts of development projects. Out-migration in the Kekreti area will be minimal because of regional development, as discussed above. At the same time, resettlement will stimulate some out-migration. Our interviews with persons in the inundation area revealed that virtually all of the men are interested in migration to better areas and are restrained only by ties to the family and the land. Forced resettlement will break many of these local ties, and thus stimulate outmigration.

In the Balingho impact area, with the probable loss of swamp rice, extensive outmigration could occur. Whole families and possibly whole communities might leave within a year or two. Their most likely destinations would be the current zones of in-migration for which people from their area have a network. The

Serekunda/Brikama area would be the main recipient. Other likely destinations would be along the Trans-Gambian highway, the southern lakeshore, and even overseas to Spain.

6.5. Public Health

Health authorities in the Member States recognize the presence of water-associated diseases in their areas of responsibility, but usually are forced by fiscal constraints to limit interventions to treatment of identified cases rather than engage in environmental control efforts. Most of the national budgets assigned to health invariably are subsumed by fixed centers in urban areas. Therefore, health changes that will result from development projects will not be easy to absorb into the structured system. Regardless, these should be anticipated in advance and budgetary allowances for increased demand for health services established in time to meet the needs that will result from the projects.

The construction of dams and development of irrigation agriculture, in altering the environment, will increase the incidence of many infectious diseases in the Gambia River Basin. Two of the three major West African diseases transmitted by water could contribute to large-scale negative health impacts of the development projects. In addition, each project will create its own set of health problems. These impacts are to be expected on the basis of past experiences with African dams, as other studies have documented. Although we discuss and therefore emphasize impacts on the incidences of major diseases, we also should mention that waterborne and water-washed diseases will tend to recede or disappear nonspecifically with the improvements in environmental sanitation and personal hygiene that should accompany basinwide development.

In the Gambia River Basin the primary concerns are for the impacts of development actions on schistosomiasis, malaria, and onchocerciasis, although other human diseases will be affected as well. These three diseases are primary public health concerns because of their prevalence, their serious implications for human health, and the difficulties in coping with them. Other diseases such as yellow fever are worth noting, but the most public health attention and actions will focus on schistosomiasis, malaria, and onchocerciasis.

Schistosomiasis is prevalent in certain regions of the basin, especially away from the river in the Upper River Division and MacCarthy Island Division of The Gambia. Currently, control measures are undertaken, if at all, only by ad hoc

programs. Malaria, combined with poor nutrition, now contributes to an unacceptable death rate of almost 450 per 1,000 children under 5 years of age in parts of rural West Africa. Although some malaria control is practiced in urban areas, rural areas rarely, if ever, experience organized control efforts now. Onchocerciasis occurs in Senegal and Guinea along the Gambia and Koulountou rivers, and has high rates of infection in areas with higher population density. Currently, onchocerciasis control is not attempted by central health authorities in Senegal or Guinea.

6.5.1. Actions and Attributes for Impact Analysis

The impacts of development projects on these and other diseases in the basin can be suggested in terms of how the environmental changes might increase or decrease the populations of the vectors (disease-transmitting mosquitoes, flies, water fleas, and snails) of these diseases. In order to assess possible impacts, we have identified various management actions and environmental attributes that will affect the populations of these vectors (Table 6.4.). These actions and attributes will be affected by construction activities, short term (less than 5 years) operational stage activities, and long-term or ongoing operational activities of development projects.

During the construction phase, the creation of construction settlements, for example, will create breeding sites for domestic mosquitoes. Similarly, road construction and, in general, deforestation will decrease the populations of tree-breeding mosquitoes. Borrow pits for dam construction will become ponds which will foster the increase of populations of mosquitoes and pond snails. Various other actions and impacts will inhibit or encourage the growth of populations of these and other disease vectors.

In the initial operational stages, additional actions and impacts will further affect vector populations. The long-term operational stages then will result in stabilized populations of these various mosquitoes, flies, fleas, and snails.

Our evaluation of these impacts on disease vector populations is subjective. An accurate assessment would require quantitative analyses based on field measurements and studies. Our qualitative evaluation, however, suggests possible directions of the impacts of development projects on human diseases -- relative to the current status of those diseases.

Table 6.4. Management Actions and Environmental Attributes to Assess Impacts on Disease Vectors

Actions and Attributes for Construction Stage Impacts on Disease Vectors

Emigration/Immigration of labor force + satellite population
Road construction; deforestation
Creation of borrow pits
Cessation of river current; marsh + pool seepage
Organic Pollution
Introduction of new vectors
Establishment of aquatic plants
Canal construction for irrigation schemes
Interruption of bi-monthly tidal action on mangroves

Actions and Attributes for Short Term (<5 years) Impacts on Disease Vectors

Removal of tidal mixing upstream from barrage
Elimination of salinity gradient upstream
Increased surface area of water
Raised water table
Increased seepage + swamp formation
Irrigation scheme canals
Water characteristics: nutrients, microbe content, temperature, etc.
Enhancement of plant growth in river
Increased human wastes
Elimination of mangroves
Land clearing road, and trail building
Influx of human population and associated activities
Changes in numbers and kinds of livestock
Changes in traditional farming practices
Changes in wildlife habitat and abundance of mammals and birds
Vegetation submergence
Beginning erosion in area of dam
Spillway; downstream irrigation canals
Emerging terrestrial vegetation; reforestation
Emerging terrestrial fauna; rodents; birds

Actions and Attributes for Long Term Operational Stage Impacts on Disease Vectors

Fresh water; absence of flow at edges; high water (1.5+ G.D.) upstream
Shallow shore; mud; reeds + sedges
Erosion patterns become permanent; swamps form
Aquatic micro- macro-fauna in equilibrium
Terrestrial natural vegetaion grows up along shore
Proximal + distant perennial irrigation; new farms, crops
Balance achieved between vertebrate + invertebrate aquatic fauna
Terrestrial fauna changes; rodents, birds, livestock, domestic animals
Human settlements; intense water contact; pollution
Deforestation
Filled reservoir; slow water flow; high water over long distances upstream
Turbulent water downstream from spillway
Formation of foreshore; shallows + mud bottom
New topography; steady state established on shore; permanent swamps
Aquatic flora reaches equilibrium
Terrestrial vegetation dense near shore; reforestation
Perennial irrigation downstream; cash crops
Fishery development in reservoir

University of Michigan Gambia River Basin Studies, 1985.

6.5.2. Impacts on Disease Vectors

The impacts of management actions and environmental changes on the vectors of various diseases involve mosquitoes, tsetse flies, black flies, sand flies, water fleas, and snails (Tables 6.5.-6.7.). These impacts will vary according to events during the construction stages, the short-term operational stages, and the long-term operational stages of the dams. We consider the impacts on the incidence of some nineteen diseases to be worth attention, although the impacts on the incidence of schistosomiasis, malaria, and onchocerciasis are of primary concern for public health planning purposes.

Our impact estimates are presented as the sum of positive and negative effects on specific actions and attributes relevant to the populations of the vectors. As such, they are qualitative and are not to be interpreted as measures of expected magnitudes of incidence of a disease. For example, a +5 for the snail B. pfeifferi (Table 6.5.) that transmits intestinal schistosomiasis is an estimated sum of the result of the impacts of the construction of Balingho. This sum represents our conclusion that the impacts of each of five factors (Table 6.4.) will increase the populations of the snail and therefore the incidence of the disease. For this vector, the five factors are:

- Fresh water; absence of flow at edges; high water
- Shallow shore; mud; reeds + sedges
- Erosion patterns become paramount; swamps form
- Aquatic microfauna and macrofauna in equilibrium
- Human settlements; intense water contact, pollution

In some cases, a +5 would be the sum of positive impacts on seven factors and negative impacts on two additional factors. These impacts are defined as positive or negative according to the current vector population.

6.5.3. Impacts on Major Diseases

Changes in disease vector populations will change the incidence of the diseases they transmit in the Gambia River Basin (Table 6.8.). The incidence of urinary schistosomiasis, intestinal schistosomiasis, and malaria probably will increase significantly. The incidence of onchocerciasis may decrease.

- The Gambia. At present, the number of persons who live and work in the standing water environments that foster schistosomiasis is limited. With Lake Balingho and irrigation perimeters, however, the number will increase by tens of

Table 6.5. Qualitative Assessment of Construction Stage Impacts on Disease Vector Populations

Disease	Vector	Common Name	Balingho	Kekreti	Kouya/ Kank'é	Kogou-Foulbe
Malaria	A. melas	Mosquito	-1	n.a.	n.a.	n.a.
Chikungunya Malaria Filariasis	A. gambiae	Mosquito	+1	+2	0	0
Malaria	A. funestus	Mosquito	+5	+5	+4	+5
Dengue Yellow Fever	Ae. aegypti	Mosquito	+2	+2	+1	+1
Yellow Fever	Ae. africanus	Mosquito	0	0	0	0
Yellow Fever	Ae. luteocephalus	Mosquito	0	0	0	0
Yellow Fever	Ae. vittatus	Mosquito	+3	+4	+4	+5
Yellow Fever	Ae. furcifer/tayl.	Mosquito	0	0	0	0
Trypanosomiasis	G. palpalis	Tsetse fly	+1	+1	+1	+1
Trypanosomiasis	G. morsitans	Tsetse fly	0	0	0	0
Onchocerciasis	S. damnosum	Black fly	n.a.	-3	-2	-2
Leishmaniasis	Ph. dubosqui	Sand fly	-2	-3	-2	-2
Dracontiasis	Cyclops spp.	Water flea	+3	+3	+2	+2
Schistosomiasis	B. pfeifferi	Pond snail	+5	+4	+3	+3
Schistosomiasis	Bu. senegalensis	Pond snail	+4	n.a.	n.a.	n.a.
Schistosomiasis	Bu. globosus	Pond snail	+4	+3	+3	+4
Schistosomiasis	Bu. guernei	Pond snail	+4	+2	n.a.	n.a.

+/- numbers indicate sum of positive and negative impacts on vector populations of effects of management actions and changes in environmental attributes. Therefore, a "0" does not signal no impact; instead, it signals a balance between positive and negative impacts.

University of Michigan Gambia River Basin Studies, 1985.

Table 6.6. Qualitative Assessment of Short Term (<5 years) Impacts on Disease Vector Populations

Disease	Vector	Common Name	Balingho	Kekreti	Kouya/ Kank'é	Kogou-Foulbe
Malaria	A. melas	Mosquito	-4	n.a.	n.a.	n.a.
Chikungunya Malaria Filariasis	A. gambiae	Mosquito	+5	+6	+6	+6
Malaria	A. funestus	Mosquito	+6	+7	+7	+7
Dengue Yellow Fever	Ae. aegypti	Mosquito	+5	+5	+5	+5
Yellow Fever	Ae. africanus	Mosquito	+2	+2	+2	+2
Yellow Fever	Ae. luteocephalus	Mosquito	+2	+2	+2	+2
Yellow Fever	Ae. vittatus	Mosquito	+7	+6	+6	+6
Yellow Fever	Ae. furcifer/tayl.	Mosquito	+2	+2	+2	+2
Trypanosomiasis	G. palpalis	Tsetse fly	0	-2	-2	-2
Trypanosomiasis	G. morsitans	Tsetse fly	-1	-1	-1	-1
Onchocerciasis	S. damnosum	Black fly	n.a.	-1	-1	-1
Leishmaniasis	Ph. dubosqui	Sand fly	0	+1	+1	+1
Dracontiasis	Cyclops spp.	Water flea	+3	+1	+1	+1
Schistosomiasis	B. pfeifferi	Pond snail	+8	+7	+7	+7
Schistosomiasis	Bu. senegalensis	Pond snail	+4	n.a.	n.a.	n.a.
Schistosomiasis	Bu. globosus	Pond snail	+9	+7	+7	+7
Schistosomiasis	Bu. guernei	Pond snail	+8	+7	n.a.	n.a.

+/- numbers indicate sum of positive and negative impacts on vector populati .s of effects management actions and changes in environmental attributes. Therefore, a "0" does not signal no impact; instead, it signals a balance between positive and negative impacts.

University of Michigan Gambia River Basin Studies, 1985.

Table 6.7. Qualitative Assessment of Long Term Operational Stage Impacts on Disease Vector Populations

Disease	Vector	Common Name	Balingho	Kekreti	Kouya/ Kank'é	Kogou-Foulbe
Malaria	A. melas	Mosquito	-3	n.a.	n.a.	n.a.
Chikungunya Malaria Filariasis	A. gambiae	Mosquito	+2	+2	+1	+2
Malaria	A. funestus	Mosquito	+6	+7	+7	+7
Dengue Yellow Fever	Ae. aegypti	Mosquito	+2	+3	+2	+3
Yellow Fever	Ae. africanus	Mosquito	+2	+3	+2	+3
Yellow Fever	Ae. luteocephalus	Mosquito	+1	+2	+2	+2
Yellow Fever	Ae. vittatus	Mosquito	+4	+6	+5	+6
Yellow Fever	Ae. furcifer/tayl.	Mosquito	0	+2	+2	+2
Trypanosomiasis	G. palpalis	Tsetse fly	+2	+3	+3	+3
Trypanosomiasis	G. morsitans	Tsetse fly	-1	+1	+1	+1
Onchocerciasis	S. damnosum	Black fly	n.a.	-1	-1	-1
Leishmaniasis	Ph. dubosqui	Sand fly	+3	+1	0	+1
Dracontiasis	Cyclops spp.	Water flea	+4	+2	+2	+2
Schistosomiasis	B. pfeifferi	Pond snail	+4	+3	+3	+3
Schistosomiasis	Bu. senegalensis	Pond snail	+1	n.a.	n.a.	n.a.
Schistosomiasis	Bu. globosus	Pond snail	+5	+4	+4	+4
Schistosomiasis	Bu. guernei	Pond snail	+5	+4	n.a.	n.a.

+/- numbers indicate sum of positive and negative impacts on vector populations of effects of management actions and changes in environmental attributes. Therefore, a "0" does not signal no impact; instead, it signals a balance between positive and negative impacts.

University of Michigan Gambie River Basin Studies, 1985.

Table 6.8. Impacts on Major Diseases

	Current Vectors/ Areas	New Vectors/ Areas
The Gambia		
Urinary Schistosomiasis	Permanent and temporary pools away from river	Pools around Lake Balingho; Irrigation perimeters
Intestinal Schistosomiasis	--	Around Lake Balingho
Malaria	Domestic Mosquitoes Saltwater Mosquitoes	Domestic mosquitoes; Surface water mosquitoes
Senegal		
Urinary Schistosomiasis	A few pools	Around Lake Kekreti; Irrigation perimeters
Intestinal Schistosomiasis	A few pools	Around Lake Kekreti
Malaria	Seasonal mosquitoes	Domestic mosquitoes; Surface water mosquitoes
Onchocerciasis	Flowing water	Remaining flowing water
Guinea		
Urinary Schistosomiasis	A few pools	Irrigation perimeters from Kogou-Foulbé
Intestinal Schistosomiasis	A few pools	Irrigation perimeters from Kogou-Foulbé
Malaria	Seasonal mosquitoes	Domestic mosquitoes; Surface water mosquitoes
Onchocerciasis	Flowing water	Remaining flowing water

University of Michigan Gambia River Basin Studies, 1985.

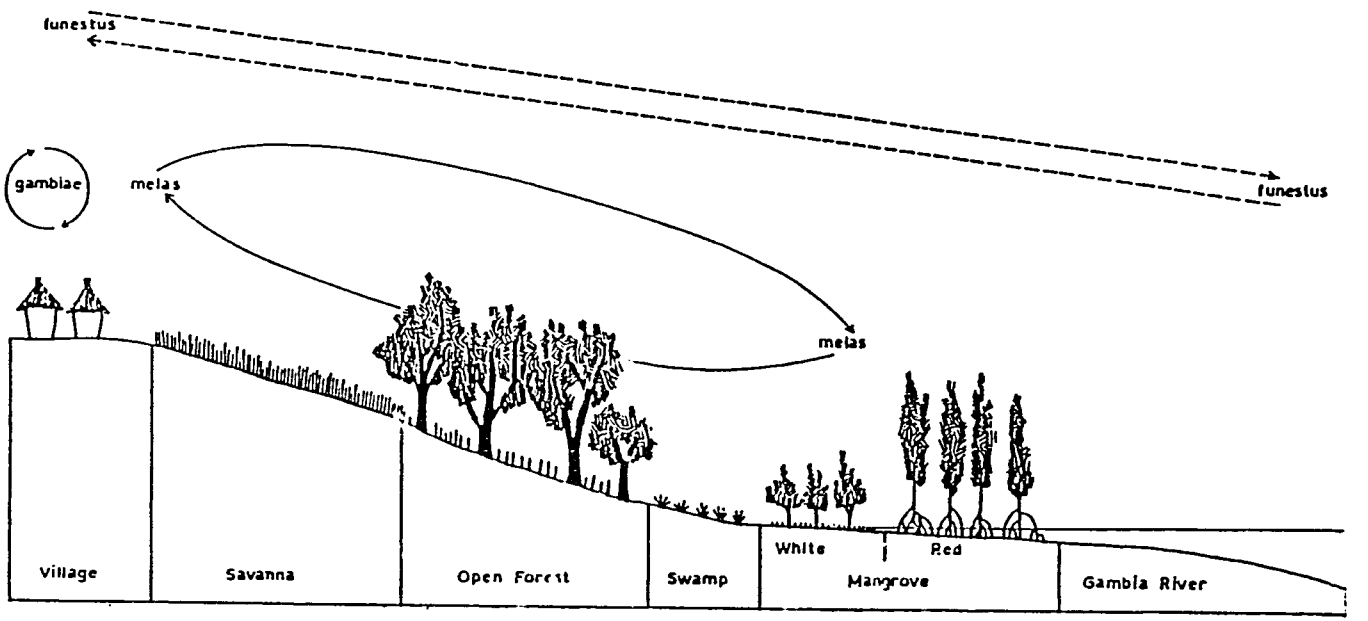
thousands. Urinary schistosomiasis is currently transmitted in seasonal pools somewhat distant from the river. It is expected to become much more prevalent because suitable pondlike conditions will form at the edge of Lake Balingho. In addition, the development of irrigation perimeters will create a new type of habitat which could add to the expected increase in the the prevalence of the disease. Intestinal schistosomiasis, which hardly exists now in The Gambia, will become established around Lake Balingho.

The incidence of malaria also will increase in The Gambia. Although the breeding environment of the saltwater mosquito vector of malaria will be reduced, the still or surface water environment of other mosquitoes will be considerably increased. The new freshwater environment, along with cessation of daily tidal fluctuations, will encourage the breeding of a mosquito, A. funestus, that is a more efficient vector of malaria than is the saltwater species, A. melas (Figure 6.3.). The domestic mosquito, A. gambiae, will become more prevalent as urban and regional development occurs.

- Senegal. Schistosomiasis currently is seasonal and not very prevalent in Senegal because of the relatively small amount of surface water and its seasonality. The formation of Lake Kekreti, however, will considerably expand the breeding environment for schistosomiasis snails. Transmission of both urinary and intestinal schistosomiasis can be expected to become prevalent and perennial. The year-round supply of surface water, along with the complicated shoreline of Lake Kekreti, also will encourage the breeding of the malaria mosquitoes and therefore increase the transmission of malaria.

Onchocerciasis is spread by the blackfly, which thrives in a flowing water environment. The formation of Lake Kekreti, therefore, which will eliminate 150 kilometers of flowing water of the Gambia, Tiokoye, and Diarha rivers, can be expected to reduce the incidence of onchocerciasis in the region. However, at the same time, the area to be flooded is but a small fraction of the total area in Senegal Oriental where the blackfly breeds. Persons resettled away from the lake therefore still may be exposed to onchocerciasis.

- Guinea. In Guinea, the incidences of the diseases will not be affected to the extent that they will in Senegal and The Gambia. Insofar as schistosomiasis is concerned, the Guinean waters are less suitable for schistosomiasis snails because of an extremely low electrolyte content. The development of irrigation perimeters in association with Kogou Foulbe, however, will to some extent encourage spread of



Flight paths of A. melas (from Avicennia swamps) and A. gambiae (domestic breeders) in a hypothetical cross-section of Lower River Division, The Gambia. Actual mosquito movements indicated with solid lines. Theoretical movement of A. funestus after construction of anti salinity barrage at Balingho indicated by dotted lines.

University of Michigan Gambia River Basin Studies, 1985.

Figure 6.3. The dam at Balingho will encourage the breeding of the malaria vector, A. funestus

the disease. The Guinean lakes also will encourage the breeding of the most efficient mosquito vector of malaria, A. funestus. Although the Guinean lakes will flood a small percentage of the blackfly breeding area, the Koundara area, where most onchocerciasis now occurs will continue to be a source of infection.

6.5.4. Impacts on Other Diseases

Impacts on other diseases will require monitoring, but will not be of continuing concern during basinwide development (Table 6.9.).

- Dracontiasis (Guinea worm disease). Guinea worm disease is seasonal with peak transmission occurring during the dry season in areas where people use surface water. The disease has reached epidemic proportions following the formation of lakes in association with other African dams, so similar outbreaks can be expected in connection with Lake Kekreti and the Guinea lakes.
- Filariasis. Filariasis is transmitted by mosquitoes, so the spread of malaria can be expected to be accompanied by a spread of filariasis. The public health importance of filariasis, however, is relatively low and probably will continue to be so.
- Yellow Fever and Dengue. Yellow fever and dengue are sporadic in the Gambia River Basin. If epidemics of yellow fever occur as a result of dam construction and river impoundment, however, they will be the result of inattention to the rules of domestic mosquito control. They will occur primarily in construction settlements. There is no known protection against dengue, but its public healtn importance will continue to be low.
- Trypanosomiasis (sleeping sickness). Trypanosomiasis occurs only sporadically in The Gambia and is now rare in Senegal and Guinea. In general, basinwide development will increase tsetse fly-human contact, especially as natural vegetation is cleared. Flooding will destroy breeding sites temporarily; these will be reestablished above the new water level. Development activities could permit an increase in incidence of the disease by disturbing the present balance.
- Leishmaniasis. This disease is limited in the basin and associated with seasonal conditions. Environmental changes in the basin will increase the humid microclimates required by the sand fly, so the transmission of a form of leishmaniasis could become year-round in certain localities.

Table 6.9. Impacts on Other Diseases

	Current Status	Impact
Dracontiasis (Guinea worm disease)	Limited/ Seasonal	Could develop around Lake Kekreti and Guinea Lakes
Filariasis	Limited	Could develop as mosquitoe populations expand
Yellow Fever and Dengue	Sporadic	Outbreaks could occur in construction settlements
Trypanosomiasis (Sleeping sickness)	Sporadic	Could develop as natural habitat is removed
Leishmaniasis	Limited/ Seasonal	Could expand with year around humid microclimates

University of Michigan Gambia River Basin Studies, 1985.

6.5.5. Systemic Impacts

The status of public health will be affected by the impacts of development actions on human populations as well as on the environment and disease vectors. As human migration and settlement patterns change and evolve, various disease patterns change accordingly. Incidence of diseases will be affected by migration patterns, construction settlements, and resettlement actions. At the same time, basinwide development should improve the status of public health in the long run.

In general, basinwide development will increase the percentage of urban areas in the basin, and the impacts on public health to some extent will depend on the effectiveness of urban and regional planning. Urbanization usually increases the transmission of diseases among humans. Development projects, in addition, will require resettlement of populations, which is difficult to manage. Resettlement, therefore, inevitably entails negative economic and health consequences. Basic health care, domestic water, sanitation, and nutrition needs are more difficult to address in the absence of existing urban areas and services.

In the short run, development projects will have a negative impact on public health because large numbers of persons will suddenly be brought together. Construction activities and settlements will attract diverse populations from throughout the basin and neighboring countries and regions. Local density of population and the disruption of natural environments will increase the incidence of many of the diseases discussed above. Unless there is careful planning, initial living conditions for the migrants will be makeshift and not conducive to personal hygiene. Crowding will lead to a high incidence of respiratory conditions and tuberculosis. The dam sites at Balingho and Kekreti are in regions where meningitis epidemics are an annual occurrance. Any absence of sanitary facilities will cause an increased frequency of enteritis, poliomyelitis, amebiasis, and bacillary dysentary, especially at the Balingho site where there already is a scarcity of domestic water supply. Cholera epidemics are a risk. The nutritional needs of all of the in-migrant population probably will not be met because fringe populations will be attracted for whom limited employment possibilities will exist. The predominance of single men in the labor population will encourage prostitution and high incidence of venereal disease.

In the long run, however, the development projects should improve the status of public health in the Gambia River Basin despite an increase in incidence of disease and short-term problems associated with urbanization and movements of people.

Urban communities have the potential for increased levels and efficiencies of health care, drinking water systems, sanitation systems, and nutrition. Especially if carefully planned in advance, the development projects will have provisions for health care, drinking water, and sanitation systems that should provide the basis for permanent systems in these new urbanized areas. The projects certainly will enable drinking water to be provided year around for both people and livestock. The reservoirs will increase the water supplies in the shallow aquifers and the irrigation networks also will make water readily available. In addition, irrigation agriculture objectives should increase the nutritional status of the basin's populations, especially as distribution and marketing structures are improved. Finally, fisheries will be established in all three Member States to provide a steady source of protein. Basinwide development, therefore, provides planners with an opportunity to improve the status of public health.

6.5.6. Economic Implications

The economic implications of the impacts of development projects on public health concern the costs of measures that should be taken to mitigate the negative health consequences. In Chapter 8, these costs are considered in the benefit/cost analyses of the dams. Here, they are summarized as impacts of the projects. The economic implications of the impacts on public health arise from the changes that development actions will bring about in the environment and that will result from the various population movements accompanying those actions.

These cost estimates assume no major in-migration of persons to development regions, beyond the construction and service populations. Although this assumption hardly seems tenable, given the probability of development of fishing populations and based on experiences with other African dams, it is not feasible to estimate the public health economic impacts of such in-migration. The costs summarized here (Table 6.10.) essentially are those that might reasonably be charged against the development projects.

The public health costs can be divided into three categories: those borne by a health unit that OMVG should establish to oversee health problems associated both with the projects and continuing basinwide development; those borne by the construction contractor during the construction period; and those borne by a health unit that should be established to handle problems of schistosomiasis associated with the development of irrigation perimeters.

Table 6.10. Costs of Public Health Mitigative Measures

OMVG Health Unit	One-Time Costs			Annual Costs		
	Balingho	Kekreti	Guinea	Balingho	Kekreti	Guinea
Health Costs Incurred by Displaced Populations	$83,000	$59,000	unk.			
Public Education Regarding Malaria, Schisto., Oncho.		> $120,000 <		$50,000	$50,000	$50,000
Anti-Malarial and Anti-Schisto Drugs and Molluscicides				$90,000	$20,000	unk.
Monitoring for Other Diseases					> $50,000 <	
Construction Contractors						
Construction and Service Populations	$31,000	$55,000	$77,000	$17,000	$16,000	$19,000

Irrigation Health Unit:

Anti-Schistosomiasis Drugs and Mollusciciding	$3,000/1000 ha
Monitoring Schistosomiasis Control	$5,800/5000 ha

> Basinwide Cost <

University of Michigan Gambia River Basin Studies, 1985.

An OMVG health unit would engage in diverse and necessary activities to mitigate the impacts of development projects on public health. Health costs incurred by the resettled populations, primarily for new wells for drinking water and new primary health care clinics, would be $83,000 for Balingho and $59,000 for Kekreti (the costs are not available for the Guinea dams). The costs of a public education program (animation rurale) would be $120,000 initially, and then $50,000 annually for each country. The costs of antimalarial and antischistosomiasis drugs and of molluscicides would be $90,000 for Balingho and $20,000 for Kekreti. Monitoring for incidence of other diseases, and being prepared for the treatment of any problems that might arise, would cost $50,000 annually throughout the basin.

During construction, the construction contractor should be responsible for the health of the construction and service populations. This would involve one-time costs of screening these populations for health problems, which would be $31,000 for Balingho (assuming local labor, e.g., without dependents, is used); $55,000 for Kekreti; and $77,000 for the Guinea dams. Annual costs during construction for malaria and schistosomiasis control would be $17,000 for Balingho; $16,000 for Kekreti; and $19,000 for the Guinea dams.

A final economic impact will be the cost of addressing problems of schistosomiasis that will arise in connection with the development of irrigation perimeters. This essentially involves mollusciciding the irrigation canals, treating cases of schistosomiasis as necessary, and monitoring schistosomiasis control in irrigated areas. The annual cost of drugs and mollusciciding amounts to $3,000 per 1,000 ha. Monitoring costs should be about $5,800 per 5,000 ha.

The only health benefit that is expected to arise from development projects is a reduction in onchocerciasis transmission upstream from Kekreti and the Guinea dams. Since the effort to control onchocerciasis in the basin is not yet in place, there is no residual economic benefit of this impact. However, the cost of any future attempt to control onchocerciasis will be slightly reduced.

In addition to the slight benefit from a reduction in onchocerciasis, to the extent that development objectives are reached public health in general throughout the basin should benefit. Improvement of transportation systems to support the various projects and infrastructures necessary to meet development objectives will have the effect of improving public health services. In the recent past, immunization schedules, health care services, and vector control have been hindered by fuel shortages, lack of spare parts and vehicle maintenance, and bad roads. Rural

areas have been denied supplies of needed drugs and the cold chain essential to vaccine maintenance has been interrupted. Basinwide development should improve this situation.

In addition, the major thrust of basin development towards improvement of food self-sufficiency should improve the nutritional status of the basin populations. This will result from improved agriculture, expansion of fisheries, and increased food supplies. Any improvement of the nutritional status of the populations will improve the status of public health in the basin.

7. MANAGEMENT ACTIONS TO ENHANCE WATER RESOURCE DEVELOPMENT

Although some of the serious impacts of the development projects will be unavoidable, others will be amenable to various management and mitigative measures. The environmental, agricultural, and social impacts of Balingho dam for the most part will be negative as well as not amenable to many mitigative measures. Anticipatory management before project implementation and during construction activities, however, can enhance some positive or potentially positive impacts of development. Mitigative measures, furthermore, will soften some of the negative impacts. The four subject-area reports detail various mitigative and management measures that should be considered by OMVG and Member State planners. In this chapter we summarize some of these important management concerns as well as introduce some systemic considerations.

7.1. Land and Water Management

Most of the impacts on land use and vegetation throughout the basin will be unavoidable, although some of the resources to be lost to inundation, such as firewood, can be exploited. Water quality can be maintained if mining activities are accompanied by strict environmental safeguards and irrigation systems are not constructed with free drainage access to the river. Wildlife can be protected if habitat is taken into consideration when project layout and activities are planned. It furthermore can be protected if strict safeguards are taken to prevent hunting and poaching. Niokolo-Koba National Park will be put in some jeopardy, so special precautions must be taken to preserve its integrity.

7.1.1. Vegetation

Four actions need to be taken to mitigate the effects of development projects on vegetation. First, provisions should be made to recover the extensive forest resources to be lost to inundation. Dam site and inundation areas should be opened to cutting for timber and fuelwood as the projects become certainties. Second, to slow the process of land degradation, reforestation and plantation programs should be undertaken. Current programs, however, have experienced numerous problems that need to be overcome.

Third, precautions must be taken to prevent unnecessary destruction of vegetation and habitat around construction sites and by the construction work force. The OMVG should formulate policies in this area and then formally work with the planners, surveyors, construction management, and the work force to implement the policies. Fourth, erosion, siltation, and revegetation control measures should be implemented at the construction sites; normally these can be made the responsibility of the contractor.

7.1.2. Wildlife

Five measures should be taken to protect wildlife. First, wildlife must be protected from hunting and poaching by the work force through enforcement of existing laws. Second, special protective measures should be taken to protect Niokolo-Koba National Park because of the proximity of the Kekreti project -- the dam and reservoir will actually intrude into the park. These would include increased surveillance, erection of barriers to keep out construction personnel, and an environmental protection education program for all levels of project personnel.

Third, a research and management program should be established to protect the manatee and sitatunga, two rare species which will be substantially impacted by the Balingho project. Fourth, the hippos should be protected. They are becoming increasingly rare in The Gambia but at the same time will increasingly become a pest species in expanding agricultural areas. Fifth, a study should be undertaken to determine the magnitude of the problem of mammalian crop pest species and to identify control measures.

7.1.3. Cooperative Regulation

Given our major conclusion that human activities will have a more significant impact on wildlife than will the construction activities themselves, means of involving the local populations in environmental protection need to be explored. Although the Terrestrial Ecology and Gambia River Basin Development report introduces means of enlisting the cooperation of local communities, systematic approaches should be developed to educate the local populations on the need for natural resource management and conservation and then to enlist their cooperation. Regulatory approaches often prove inadequate.

7.1.4. Parks

A regional master plan for long-term development of Senegal Oriental should be prepared because of the implications of the Kekreti project for Niokolo-Koba

National Park. Because of the proximity of Kekreti dam and reservoir to Niokolo-Koba National Park, OMVG should cooperate with the park staff and Senegalese government agencies in conducting a detailed impact study to assess the implications of the Kekreti project and to formulate management and mitigative measures. This impact study should be conducted before the decision is made to initiate specification planning for the project.

In addition, additional wildlife sanctuaries on selected Gambia River islands should be considered. Finally, the Balingho project, because of its impact on wildlife habitat, should provide some form of support for Kiang West National Park.

7.1.5. Water Quality

Most of the effects of development projects, especially of Balingho, cannot be mitigated. However, a number of measures can be taken to protect the river banks and limit sedimentation during the construction period. In addition, human settlements and activities along the river should be controlled to prevent deforestation and pollution of the river.

Release of toxic substances and nutrients to the river from farming activities should be mitigated by careful control of the use of pesticides, herbicides, and fertilizers to improve agricultural productivity (such controls are difficult to implement, however, as experiences in Europe and North America illustrate). When mining is initiated, stringent environmental safeguards will be needed to prevent acid runoff and toxic metal contamination.

The OMVG should be given the charge of setting up and conducting a monitoring program and then of setting water quality standards to be maintained during basinwide development. An immediate objective should be to establish a pilot water quality monitoring system. This will provide a diagnostic tool to assist in the design of a permanent basinwide system for water quality management and planning.

7.1.6. Controlled Water Flow

Management of the water flow from Kekreti will be needed to balance the needs of hydroelectric turbine operation against irrigation needs and control of the salt tongue intrusion. The impact of altered stream flows on water quality also should be taken into consideration. Release of water should match as closely as possible the existing pattern of annual streamflows.

Perhaps some consideration could be given to a controlled annual flood near the end of the wet season. This would enable many aquatic organisms to maintain their

life cycles. It also might enable some flood recession agriculture to be maintained that otherwise might be lost. Thus, dam and reservoir management should be coordinated with agricultural management policies and other downriver and reservoir uses. In a systems context, the tradeoffs with hydroelectric power generation might weigh heavily in favor of such coordinated management.

7.1.7. Precise Contour Mapping

Particularly important for assessing impacts and refining benefit/cost analyses is contour mapping at intervals of 0.1m. It is especially important to map the existing floodplains and to determine the inundation and drawdown areas of Lake Balingho precisely. This will help clarify impacts on swamp and flood recession agriculture as well as help plan irrigation systems.

7.1.8. Drawdown Agriculture

The drawdown zone created by reservoir water releases during the dry sea can be a productive agricultural zone. Over 700 km^2 of drawdown will be created with Balingho and Kekreti alone. However, effective use of the drawdown zone for agriculture will require planned management of the release of water so that, for example, crops are not inundated by early refilling of the reservoirs. Uses of the drawdown zones should be monitored and, if necessary, controlled. Wildlife, livestock, farmers, and fishermen may have conflicting uses. Uncontrolled use of drawdown zones also increases sedimentation in reservoirs.

Because of the distinctive nature of the drawdown areas, separate management and agriculture infrastructures will have to be established by OMVG and the Member State governments. Management of the drawdown areas must be coordinated with management of dam and reservoir operation. Drawdown management responsibilities will include land use policies along the shores of the reservoirs, recommendations for crops to be cultivated, development of appropriate technologies such as bunding schemes for recession agriculture (double cropping is achieved around some reservoirs), measures to insure that livestock have controlled access to water supplies, and measures to ensure the health and sanitation of the local populations. (Living on or near ground that is damp much of the year and water that is shallow poses hazards.)

Essentially, drawdown management policy should be a primary charge to OMVG or appropriate Member State agencies. The drawdown areas will be a significant resource, but will require management among conflicting uses in order to exploit

their potential. They will be used for agriculture, livestock grazing, and even fishing. In addition, wildlife will compete as they seek access to the reservoir water. Given the development objective of 70,000 ha of irrigated agriculture, planners should not overlook the potential of the 70,000 ha of drawdown area at Lake Balingho and Lake Kekreti.

7.2. Agricultural Management

Agricultural management should recognize that rainfed production will continue to be the basis of domestic food production until such time as the constraints to irrigated agriculture are eliminated. Investments in agriculture must be made both to improve the productivity of rainfed crops and to design irrigation systems more suitable to the Gambia River Basin than those currently proposed. The potential benefits of agricultural management can be best realized if appropriate management considerations are taken to cope with constraints at the technical, administrative, structural, and household levels. The potential for foreshore farming in the drawdown area is significant, as mentioned above, and can be exploited with effective dam and reservoir management.

As significant expansion of irrigated agriculture in the basin is dependent on the construction of Kekreti, a number of years are available for monitoring and evaluating current irrigation projects in order to analyze the constraints we have identified and to formulate more appropriate models for irrigation expansion. In the meantime, resources should be allocated to developing and strengthening various agricultural institutions, supporting services, and local managerial abilities essential to successful expansion of both rainfed and irrigated agriculture. An important requirement or condition would be maximum community participation in agriculture management.

Successful development of agriculture, especially irrigation agriculture, will require OMVG to establish a monitoring unit to compile and evaluate economic and performance data, population and labor data, administrative data, and sociological data. Its purpose would be to determine if goals are being met, identify problem areas, and propose management and policy changes.

7.2.1. Agricultural Policy

Achievement of agricultural objectives will require the Member States to give high priority to effective agricultural policies. Planners first of all should consider

a wide variety of crops, new as well as traditional. Second, the price structures should incite farmers to produce. Third, policies to allocate resources must strengthen agriculture infrastructures -- research, transportation, food processing. Fourth, credit must be made available, as more sophisticated production methods will require the availability of credit; farmers must have the resources to adopt new technology.

7.2.2. Monitoring and Rehabilitation of Current Projects

A monitoring and evaluation unit should be established to monitor the effects of existing irrigation projects on farmers. Production data, assessment of costs, and constraints to participation and efficiency over time should be analyzed.

Currently, The Gambia and Senegal have considerable underutilization and, in some cases, abandonment of existing irrigated perimeters. A policy for the rehabilitation, where economically feasible, of these perimeters should be formulated. This would provide an opportunity to develop situations to the underutilization problem in advance of further expansion of irrigation.

7.2.3. Irrigation Agriculture

Given the critical need for the Member States to achieve greater food security, effective development of irrigation agriculture in the long term will be an important means. However, most current irrigation models stress large-scale projects. In the short term, planners should give more consideration to small-scale models that incorporate irrigation into existing farming systems. At present, returns per unit of investment are higher on less capital-intensive schemes. An intermediate goal, therefore, would be to aim for self-sufficiency of individual farm families.

7.2.4. Improved Rainfed Rice Cultivation and Agricultural Research

Since rainfed rice production will remain an important food source for the Gambia River Basin for the short to medium term, considerable effort needs to be made to increase productivity. Improvements in traditional or rainfed rice cultivation, improved moisture control, the use of inputs, and improved varieties should be tested at the farm level to determine the potential for improving current farm productivity.

Development of applied agricultural research also is essential to improved agricultural production and greater recourse to irrigation and drawdown agriculture. Irrigation crop considerations should not be limited to rice, as other crops can also be economically profitable. Therefore, existing agricultural research

institutions need to be strengthened. Research should address not only the traditional agronomic factors such as variety, yield, and pest management but also the socioeconomic variables which influence the total production environment. Current projects are beginning to take some of these objectives into account.

7.2.5. Training of Extension Agents

Well-trained field agricultural extension agents are in short supply. Given the anticipated level of management and technical skills required for the future, improved training programs are a necessity. Agents should be trained to be familiar with the specific needs of farmers and they should assume the role of providing advice and assistance rather than that of input distributors and credit collectors.

7.2.6. Marketing

Markets and marketplaces for cereal crops are central to the shift from extensive to intensive agricultural systems. Without adequate marketing infrastructure and services, there will be substantial difficulties in the movement of commodities from urban areas to rural areas and vice-versa. Improvements in marketing systems for cereals should address the needs of farmers, traders, and governments.

Farmers:

i) Producers should be allowed to sell to whom and where they want as long as they pay production debts. No limit should be set on quantities that can be sold in the private market.

ii) Hulling and threshing equipment should be made available to groups of producers and/or traders. Credit for such machinery should come out of a special fund, perhaps from a local bank, not out of project working capital.

Traders:

i) Traders should be eligible for bank credit for small scale hulling and milling equipment, construction of storage facilities, and investment in transportation. Government regulations limiting amounts of paddy or rice traders can handle should be discontinued.

ii) Private traders should be encouraged to participate in the market for agricultural inputs.

Government:

i) Public agencies should continue to offer a market outlet for paddy as a means of debt repayment, but farmers should also be allowed to sell paddy where they

choose -- to contract millers or private traders -- at prices which cover marketing costs.

ii) The governments may continue to offer an official minimum producer floor price and monitor private trade so that farmgate and consumer prices accurately reflect the cost margins incurred by producers and traders. If retail prices rise to unacceptable levels, the governments should stabilize prices by increasing market supplies, not through price controls.

7.2.7. Milling and Storage

Programs should be designed to improve milling and storage at both the farmer and trader level. The inefficient use of existing milling equipment is a constraint to increasing the quantity of production flowing to market. Storage facilities are very poor and need to be improved. Government regulations that discourage ownership of private mills and private storage facilities should be discontinued.

7.2.8. Risk and Allocation of Resources

There should be continuing examination of our conclusions that allocation of resources and assumption of risk at the household level will be major constraints to the expansion of irrigation agriculture. This can be done in association with monitoring of current projects and the rehabilitation of existing perimeters.

7.2.9. Livestock

Livestock will continue to play an important role in basin farming and nutritional systems. Although our studies focused on crop agriculture, agricultural management must include livestock considerations and address inherent conflicts in land use, labor, and water use between crops and livestock. Current irrigation perimeter models do not include livestock; even though the LRDC model assumes oxen traction, it has no provisions for the production of fodder or quartering of animals. Irrigation schemes, futhermore, should provide livestock with water access. If irrigation schemes assume use of animal traction to reduce labor demands, they should introduce livestock infrastructure considerations such as production, storage, and delivery of fodder, training of farmers to use and care for the animals, and veterinary services and breeding facilities.

7.2.10. Transportation

Basin development projects will provide the opportunity to improve the transportation systems essential to effective input and marketing structures,

especially in the irrigation expansion zones. Effective planning and some additional allocation of resources should be made in order to take advantage of this opportunity. Specifically, roads should be improved between Gouloumbou and Missira, between Maka and the Sandougou Bolon production sites in Senegal, and along the entire north and fareastern banks of the river in The Gambia.

7.3. Fishery and Aquatic Resource Management

Preservation of existing fisheries and exploitation of potential reservoir fisheries will require careful planning and sustained management. The estuary must be protected from pollution to preserve its existing marine and shellfish fisheries. The reservoir fisheries will require extensive management infrastructures if the standing crops of fish are to reach their potential and if the fisheries are not to be overfished. The water quality of the reservoir must be maintained in the face of sedimentation, especially during the construction period, the uncontrolled growth of aquatic weeds, and pollution from agricultural chemicals. A significant potential for increasing fishery production for both commercial and subsistence purposes is to introduce aquaculture into the reservoirs and the irrigation networks.

Realizing the potential of the basin fisheries will depend on water resource management throughout the basin. Fundamentally, it requires national environmental policies to ensure and protect water quality. It furthermore requires management of dam and reservoir operation to assure oxygen saturation of reservoir discharge water, avoidance of nitrogen supersaturation, and maintenance of minimum streamflow and reservoir pools levels to meet fish species' requirements for spawning and feeding.

One important but short term consideration is to plan to exploit the initial bloom of fishery productivity when the reservoir forms. Subsequent productivity will stabilize at a lower level. This will provide a one time source of developmentcapital. It also will provide an opportunity to train the local populations in fishing techniques which would provide a long-term source of livelihood for some of the persons displaced by the reservoir. With advanced planning and training in addition to control of in-migration of fishermen from elsewhere, the fishery could provide a solution to some resettlement problems.

7.3.1. Standing Crop of Fish

Measures should be taken to mitigate the harmful impacts of various development actions on the water quality and forage bases that support the standing

crop of fish. A program should be instituted to monitor fish stocks and water quality and, through catch statistics, to evaluate the actions that are taken. Research could be undertaken to improve the standing crop and the quality of the catch. Management of the stocks to be favored would introduce planktivorous small fish as food for valuable predators as well as control of competitors and predators. Food supplies would need to be assured for small bolons, ponds, and canals. Stocking programs to maintain and control populations will be required.

An assessment of the marine fish and shellfish stocks in the estuarine and coastal waters should be made in order to estimate potential yields and the potential value of this resource. Such an assessment would help in a more precise analysis of the economic impacts of Balingho.

7.3.2. Regulation of Fishing

Fishery management must regulate fishing pressure for maximum fishery productivity. The reservoir fisheries will attract an in-migration of fishermen, which could easily result in overfishing of the standing crops of fish. Overfishing can damage species stocks and thereby reduce future catch potential. (Underfishing also reduces catch potential, so open fishing seasons might be required.) As reservoirs initially will have an abundance of fish before the standing crops stabilize at lower levels, overfishing can easily develop. In addition, annual drawdowns will increase fish concentrations and therefore increase the likelihood of overfishing.

Fishery policy, therefore, should allocate the fishery resources to ensure maximum sustainable yields. Based on continual monitoring of the standing crops of fish, the number of fisherman entries, the number of fishing canoes, and the kind and amount of gear per entry should be regulated. A licensing system would be a sound basis for fishery management. It also could improve catch statistics, which are essential to sound management.

7.3.3. Fishery Infrastructure

An array of fishery support services should be planned to enhance the economic benefits of the fisheries, especially for subsistence and artisanal fisheries. These should involve extension, credit, handling, processing, storage, transport, and marketing. For example, fish landings should be established with transportation connections (land and water) to markets. At present, inefficient marketing considerably reduces the value of the catch. Populations should be educated in fishing techniques and fish handling, processing, storing, and cooking for maximum nutritional benefits. Some fishery extension services might be provided.

7.3.4. Reservoir Fishing Safety

Fishery management also should anticipate the change from riverine to reservoir fishing. The fishing canoe of the river may need improvement to assure stability and safety afloat in the expanded open waters of the reservoir. Whereas in river fishing the bank typically is nearby, lake fishing may require extensive travel to fishing grounds as well as to catch disposal sites.

7.3.5. Aquatic Weeds

Monitoring of aquatic weeds is required so that they can be controlled before they become too widespread. Once well established, aquatic weeds in reservoirs are difficult or even impossible to control. Some local control efforts are possible. The manatee and hippo could afford valuable help in this regard. The current freshwater fish species do not include a vegetarian fish useful in weed control, but introduction of an exotic fish for this purpose should be considered only with great caution.

7.3.6. Protection of the Estuary

Rigorous pollution control will be needed if the remaining estuary is to survive as a biologically productive and recreational resource. A modern domestic sewage system and treatment facility will be obligatory for Banjul if Balingho is built. A system of monitoring the estuarine pollution load will be needed.

7.3.7. Development of the Marine and Estuarine Fisheries

A program should be established to evaluate, develop, and manage the fishery resources of the coastal waters. These currently seem to be underexploited. In addition, The Gambia is not realizing its fair share of these resources. We estimate that The Gambia now receives about 12% of the value of the fish taken from its waters by industrial fisheries. Problems associated with fishing methods, handling, distribution, and marketing need to be addressed in order to realize the potential of these fisheries.

7.3.8. Aquaculture

Aquaculture represents an opportunity for significant increases in fishery production in the manmade lakes and irrigation networks. The estuary could have aquaculture potential as well. Experiments elsewhere in Africa should be monitored, for example in Ivory Coast, Nigeria, Kenya, and Egypt. Aquaculture development usually requires financial support, so guaranteed loans may be

necessary. Aquaculture can be extremely productive. In addition, the harvest can be timed to meet market demand and to delivery schedules.

7.4. Urban and Regional Planning

The combined impacts of construction and construction settlements, resettlement, migration, extensive irrigation projects, and transportation systems will create an opportunity for coordinated regional planning. Resettlement planning can mitigate the disruptive effects of dislocation if agricultural, community, employment, and minority needs are taken into consideration. Resettlement communities can be planned in association with irrigation perimeters. In-migration can be anticipated and planned for. Alternatives can be provided to minimize out-migration. Food assistance must be provided during transition periods.

Public health measures can be taken to control the transmission of schistosomiasis and malaria as well as other diseases, including sanitation measures, prevention and treatment of disease, and vector control. Safe water supplies must be provided. Health education should be undertaken. National health budgets can be increased.

7.4.1. Resettlement

The populations affected generally are those who will benefit least from the construction of dams. Types of resettlement need to be distinguished, along with their associated costs. Forthright communication and meetings with the affected populations and their leadership are required once plans have been formulated. Host populations should be considered as well, especially in regards to land distribution and ethnicity.

The needs for the Balingho project should be investigated, as our study suggests some resettlement will be necessary. Compensation of loss of rice lands also should be considered. The needs for the Kekreti project should be investigated further than they already have been, as some factors such as loss of income from nonagricultural activities have not been considered in previous studies. Decisions should include which villages will be clustered and which separated in new locations. A policy on ethnic homogeneity, furthermore, will generate less conflict and more cooperation. Salemata will need to be partly rebuilt. In general, trading, marketing, and service links will need to be reestablished in the region. The affected villages in Guinea should be consulted on site selection. Planned resettlement to new communities for

work on irrigation perimeters will depend on the strategies adopted with regard to level of technology and amount of labor required.

OMVG should, therefore, commission a follow-up resettlement study for each dam before funding is sought. In addition, OMVG should establish a resettlement monitoring unit to implement the recommendations of the resettlement studies. A resettlement study must address systemic considerations far beyond just making provisions to feed, support, and relocate populations whose homes and lands will be lost. As thousands of persons will be involved, resettlement plans should be formulated in conjunction with planning for irrigation development, development of the fisheries, and exploitation of the drawdown areas. Identification of areas suitable to relocate populations requires planning in a regional context, in terms not only of land use but also of the sociological characteristics of the relocated and host populations.

Special consideration needs to be given to the needs of the populations during the transition or resettlement period, as outlined by Thayer Scudder (1985). Provisions must be made to meet the food needs of the populations during the transition period. Numerous public health needs will require funds, staff, and facilities. Time frames are especially important. For example, persons may be relocated on new irrigation perimeters but considerable delay may be encountered before they are operational. Even if persons are relocated on immediately cultivable land, they will need to be supported for a year or so before they become agriculturally self-sufficient. The problems are more than material. As Scudder observes, care must be taken that the relocated populations become self-sufficient rather than dependent. In sum, resettlement issues require specific attention because of their sociological as well as economic implications.

7.4.2. Construction Settlements

OMVG and Member State government agencies should participate in planning the construction settlements. Several of these should be planned as permanent settlements. They could become models for regional development. Thus, OMVG and Member State planners should participate in site selection, plans, and specifications. They should share costs so that the construction community could be made permanent. Such facilities as health centers for the construction personnel could be established with this in mind. Other facilities could be designed for conversion after dam construction to other uses, such as regional veterinary and education centers. The added cost of assuring permanence would be borne by the governments, perhaps with donor help aimed at a demonstration model community.

7.4.3. Construction Planning

Particular attention needs to be devoted to construction planning. At one level, there will be systemic implications. Will construction hiring conflict with ongoing needs for agricultural labor? Will in-migration be unnecessarily stimulated? At a practical level, numerous problems must be addressed. An important decision has to be made concerning whether or not to clear the reservoir area extensively. Provisions should be made to harvest the wood that will be flooded. Siting, roads, etc., should be planned with a consideration for the impacts on vegetation. Wildlife should be protected wherever feasible. In general, OMVG and the relevant Member State agencies should participate in construction planning and operations in order to help mitigate negative impacts wherever economically and technically feasible.

7.4.4. In-migration

In-migration to reservoir shores should be anticipated and regulated. Once the high-water and low-water shorelines have been identified (which can be done effectively only after the reservoir fills), a land-use plan should ensure that development is orderly, well-founded, and environmentally harmonious.

In-migration to supplement local labor supply for irrigation projects should be controlled to avoid conflicts with local populations. These projects should be dispersed geographically, paced in rhythm with local population growth, and made contingent on local efficiency in irrigated farming.

7.4.5. Out-migration

Measures should be taken to stabilize rural populations during development. Food supply needs to be assured as agricultural options become limited and rice fields lost. School systems should be decentralized. Local people should be trained to enable them to compete for jobs, and they should be trained on site whenever possible. Incentives and amenities, especially emergency health care and schooling for children, should be provided to keep the skilled work force stable.

7.4.6. Historic Sites

Some archeological, historic, and cultural sites will be placed at risk by inundation and irrigation development. A basinwide commission should be created with authority to identify and preserve sites of historic and scientific value.

7.5. Public Health

Under present budgetary conditions, the Member State governments will be unable to meet the health needs of development projects. Early liaison and planning sessions between OMVG and Member State health services will be required to define the role and responsibilities of OMVG with respect to public health implications of development projects. A health unit would be established within OMVG's technical staff to establish close liaison with the World Health Organization and the health ministeries of the Member States. An initial responsibility should be to standardize and systematize recording, compiling, analyzing, and publishing epidemiological statistics of the Member States. The unit should initiate a long-term program of health surveillance throughout the basin, including surveillance of food availability and nutritional status. This unit must participate from the very beginning in plans to build the dams to assure medical security in the construction villages. It should be involved on an equal basis in planning for all development projects.

7.5.1. Mitigation Measures

Certain broad-scale interventions affect transmission of many infections. These should receive priority attention from planners. Categories include installation of safe water supplies, environmental sanitation, and health education. Chemoprophylaxis and vector control measures should be tailored to specific infections.

Water-associated infections are major causes of morbidity and mortality in rural communities in hot climates. These disease problems, however, will respond to improvements in water quantity, quality, availability, and reliability. Efficient and rational resource allocation and planning for water supply should be required of development planners and construction contractors.

Mass chemotherapy can combat certain major infections, especially malaria. Vector control measures should be used against snails, mosquitoes, black flies, tsetse flies, sand flies, and water fleas as circumstances warrant and cost-effectiveness allows.

Health education or animation rurale programs should be established at the community level with participation of the primary health care worker.

7.5.2. Management Schemes

Ongoing management programs should be established for schistosomiasis, malaria, and onchocerciasis. Management of schistosomiasis involves choices among

chemotherapy, snail control, sanitation and water supply, and education measures. The specific program chosen will depend on commitments of health delivery systems and government officials. Management of malaria relies on chemotherapy and vector control, and a number of different programs that have been designed for various levels of protection can provide the basis for programs designed specifically for the basin. Management of onchocerciasis is costly, but an international control program currently being undertaken by the World Health Organization is available to be extended to the basin if financing can be obtained.

7.6. Basinwide Policy

The Member State governments should develop basinwide environmental and public health policies, along with implementing legislation, to assist OMVG in guiding basinwide development. Our studies indicate a need for legislation in regard to water control, environmental protection, wildlife and natural resource management, and fisheries management. OMVG should be charged with monitoring the aquatic and terrestrial environments, in cooperation with Member State agencies and with links to other West African institutions.

An action plan for basin development should be accompanied or preceeded by legislation of the Member State governments that would establish a basinwide environmental policy and provide for water resource management across national boundaries. The relevant international policy and legal framework requires a uniform four-country policy with implementing legislation. The legislation would coordinate the efforts of the many government ministries and agencies involved in national aspects of resource management.

In a basinwide context, neglect of fundamental international policy issues can seriously limit or even negate development. The following topics would be inherent in a basinwide environmental policy:

- Air quality criteria and standards;
- Water <u>quality</u> criteria and standards, including downstream riparian rights;
- Water <u>quantity</u> criteria and standards, including downstream riparian rights and minimum low-flow discharges to meet requirements of aquatic life, wildlife, livestock, agriculture, and local populations;
- Soil quality criteria and standards, including conservation and erosion control;

- Conservation of forest and grassland resources, including reforestation and enhancement of forest resources;
- Protection of rare and endangered species;
- Conservation of wildlife, including regulation of transport and sale of wild animal products and enhancement of wildlife preserves;
- Conservation of aquatic life, possibly including innovation of an aquatic preserve;
- Communication network improvement, including telegraph, telephone, roads, and public transport internationally within the basin;
- Frontier control, including veterinary and public health considerations;
- Food and agriculture product quality control, including reference to spoilage, pesticide load, and transport of insect pests and diseases;
- Solid and liquid waste disposal standards and systems;
- Navigation aids and water safety code, with special reference to those parts of the river that are destined to become an international waterway and to the manmade lakes that will be formed;
- Identification, classification, and preservation of archeological, cultural, and historic sites;

Rational and integrated development of the Gambia River Basin to its fullest rich potential requires that adequate attention be given to these policy matters.

8. BENEFITS AND COSTS OF DEVELOPMENT PROJECTS

In this chapter we summarize and, where possible, quantify the major impacts, positive and negative, of the proposed river basin development projects. Although we use a benefit/cost framework, we should emphasize that this is only a preliminary analysis. It is to be used by decision makers to explore the economic implications and to identify the important trade-offs that must be made.

Considerable additional information and analysis will be required before policy can be formulated for actual investment decisions. Many important impacts are not quantified because current information is insufficient. Further investigation, beyond the scope of our project, is required. In addition, some of the assumptions underlying this analysis will need to be reassessed as new information becomes available. Given the important gaps in information as well as uncertainties over precise phasing of various development options, therefore, this analysis should not be viewed as definitive.

Our analysis, however, provides a framework that should be extremely useful to OMVG as a basis for ongoing evaluation of development options. The OMVG currently has at its disposal a benefit/cost computer program tailored to its specific needs. This program will allow OMVG staff to refine these benefit/cost analyses as the basinwide data base improves. This computer program also will allow OMVG to conduct a variety of sensitivity analyses on key variables and to assess the impacts of changes in underlying assumptions.

8.1. Framework for Analysis

When the Gambia River Basin Studies were initiated, the proposed five dam strategy was established as the framework for our socioeconomic and environmental analyses. Recent studies and consultant reports, however, have stimulated a reexamination of the five dam strategy, particularly with regard to phasing and sequencing of the dam projects. Initially, Balingho Dam was to have been constructed first to provide water for irrigation, salinity control, and a bridge across the river for the Trans-Gambia Highway. Balingho was to be followed by Kekreti Dam, which would produce electricity and permit extensive irrigation development. The Guinea dams were to follow at some unspecified time; they currently are in the prefeasibility phase. As yet there are no specific plans or cost estimates for the Guinea dams.

Our analysis is based on a series of assumptions concerning the hydrology of the operation of the dams and reservoirs. In the case of Balingho Dam, we assume that a reservoir approximately 716 km^2 during the wet season will be created. As discussed in Chapter 3 (Table 3.8), this reservoir will inundate an estimated 11,000 ha of presently cultivated swamp rice. An additional 3,500 hectares (ha) of swamp rice production upstream of the reservoir will be lost due to attenuation of tidal action. Downstream of the proposed dam an estimated 600 ha of swamp rice will be lost due to tidal amplification. We furthermore assume that, because of concern over reservoir height and acid sulfate soils, Lake Balingho will only be able to provide water to irrigate a maximum of 5,000 ha. At the same time, the potential drawdown area of the reservoir will be some 400 km^2. Some of this area would have the potential for recession agriculture and livestock grazing. Although at this time it is not possible to determine the area or feasibility of such potential, this drawdown area will be a benefit that will accrue to the Balingho project.

Kekreti Dam will create a reservoir of 338 km^2, which will inundate some 2,200 ha of currently cultivated land. We assume, however, that Lake Kekreti will be able to provide sufficient water for the irrigation of at least 70,000 ha. Autonomous operation of Kekreti (the original feasibility study for Kekreti Dam assumed it would be operated in tandem with Balingho Dam), furthermore, would seem to allow the simultaneous achievement of the three objectives of hydroelectric power generation, salinity control, and irrigation. While there are trade-offs between the latter two objectives, they do not become significant until more than 30,000 ha are irrigated. [According to the recent study of the autonomous operation of Kekreti Dam without a Balingho Dam (HHL, 1984), with 30,000 ha of downstream irrigation the saltwater tongue can be kept between 149 and 162 km -- below the current 198 km penetration in normal wet seasons.] In addition, the Kekreti reservoir will have a drawdown area of about 300 km^2, some of which will have agriculture and grazing potential.

Some of the basic assumptions of the initial engineering feasibility studies for Balingho and Kekreti have now been reexamined, in particular those with respect to the extent and timing of irrigated agriculture development. In the case of Balingho Dam, Coode and Partners originally estimated that some 24,000 ha could be irrigated with water from the reservoir. In light of considerations of maintaining minimum reservoir levels to avoid soil acidification, however, it is now estimated that only 5,000 ha might be irrigated from Lake Balingho (Rhein-Ruhr, 1984).

Furthermore, most, if not all, of this same 5,000 ha, it seems, could be irrigated with the water released from Lake Kekreti. Thus, no irrigation benefits, strictly speaking, are attributable to the Balingho project.

Furthermore, the study of the autonomous operation of Kekreti Dam indicates that the augmented downstream flow from Kekreti could be utilized in the dry season to restrict the salt tongue to the lower reaches of the Gambia River, depending on the amount of land irrigated. This would seem to lessen the need for Balingho Dam as a salinity barrier, at least in the short run. Salinity control, therefore, allowing for some continued swamp rice production, could be considered a potential benefit accruing to the Kekreti project.

In regards to expansion of irrigation agriculture, we have come to ask serious questions about the economic viability of expanded irrigation at the pace and on the scale envisioned in development plans. Our review of recent irrigation experiences in The Gambia and Senegal Oriental suggests that the existing constraints will limit the capacity of current large scale schemes to achieve production objectives. In the short-term and medium-term (less than 25 years), from a benefit/cost perspective large scale irrigation of the type proposed for the Gambia River Basin remains a marginal proposition. Few, if any, residual benefits from irrigation projects would cover any significant portion of the costs of dam construction.

In view of this conclusion, we treat benefit/cost analyses of dam projects separate from benefit/cost analyses of expanded irrigation. The costs of the dams should be justified by benefits from hydroelectric power generation and transportation alone, without assuming irrigation benefits. While we feel that it is appropriate to assess the potential benefits and costs of dam construction as separate issues in this analysis, we also recommend that the eventual decision making be based on a more regional and encompassing analysis than we are able to provide at this stage. That is, both generation of hydroelectric power and improvements in transportation will have regional implications beyond the Gambia River Basin which should be considered in final benefit/cost analyses.

8.2. The Economic Analyses Conducted

We make four preliminary benefit/cost analyses of the proposed Gambia River Basin development projects:

- Balingho Dam
- Kekreti Dam

- Balingho Dam and Kekreti Dam in tandem
- Irrigation Development

The time frame for each development project is 50 years. All benefits and costs are estimated using economic or shadow prices (that is, the real or actual costs to society). An exchange rate of 4 dalasis/1 U.S. dollar and 450 CFA/1 U.S. dollar is used throughout all analyses.

Because feasibility studies have not been made for the Guinea dams, we are not able to include them in our quantitative analyses of development options. However, some costs associated with construction of the Guinea dams and implementation of irrigation agriculture in Guinea are identified and discussed separately.

In addition to estimating direct benefits and costs, we also discuss a series of important but unmeasurable effects of dam implementation. In some cases the impacts, negative or positive, can be identified but not quantified. The importance of these factors remains an empirical question.

In order to assess the economic implications of the four development projects, both internal rates of return and net present values of benefits and costs are calculated for each project. The internal rate of return is a measure of the maximum interest rate of return to society that a project could pay for the resources invested in that project. In other words, it is the rate of return on the capital while invested in the project -- in our analysis, 50 years. The formal selection criterion for the internal rate of return measure of project worth is to accept or fund all those projects for which the internal rate of return is above the opportunity cost of capital. We have estimated the opportunity cost of capital to be 10 percent. If we use this as a cutoff point, all projects with an economic rate of return higher than this rate are, in theory, positive investments; projects with economic rates of return less than this rate are, from a strictly economic point of view, not viable.

The net present values of the costs and benefits associated with the four development projects are also calculated, using a 10 percent opportunity cost of capital. Calculation of net present value is essentially a technique by which future benefits and costs are reduced to their present worth. Net present value is the value to society now of the income streams generated by an investment. From a project evaluation point of view, it is desirable to have net present value of benefits greater than the net present value of costs. The formal economic criterion for this project evaluation technique is to accept projects with a net present value greater than zero when discounted at the opportunity cost of capital.

We have also conducted a limited number of sensitivity analyses. The number of people -- if any -- to be resettled due to the construction of Balingho Dam and the formation of Lake Balingho remains to be determined. In order to assess the importance of the issue of resettlement to our economic evaluation we include in a sensitivity analysis a minimum population to resettle of 15,000. In addition, at the request of OMVG we conducted two other sensitivity analyses. A discount rate of 6 percent (instead of 10 percent) is also used to calculate the net present values of the four development projects. A yield of 7.5 metric tons per hectare (MT/ha) per season (instead of 4.5 MT/ha and 4.0 MT/ha in the dry and wet season respectively) is used to evaluate the current irrigation development models.

8.3. Benefit and Cost Factors of Dam Construction

In order to calculate internal rates of return and net present values for development projects, known costs and benefits must be specified or assumed. Our values are taken from the best available estimates or have been taken from our own analyses. Our use of secondary sources to estimate costs such as for dam construction and benefits such as for transportation and hydroelectric power should not suggest we endorse their quantitative methodologies. Indeed, in some cases we have serious reservations. However, as investigation of these variables was beyond the scope of our study, for our purposes here we use their estimates. As more information becomes available, OMVG staff can change these values to recalculate the internal rates of return and net present values.

8.3.1. Dam Costs

Construction, operation, and maintenance costs. The basic construction, operation, and maintenance costs of the two dam projects are taken from engineering cost studies. In the case of Balingho, construction costs were originally estimated by Coode and Partners, The Gambia Estuary Barrage Study (1979), at $103 million and reevaluated in 1984 at $128 million. Coode and Partners estimates of dam and bridge structure operation and maintenance costs are presented in dalasis at mid-1978 prices. To convert them to dollars an average 1978 exchange rate of 2.05 dalasis/1 U.S. dollar is used. These figures are then doubled to reflect an assumed rate of inflation of 12 percent over the last six years. These annual costs are estimated at $371,000.

In the case of Kekreti, the economic costs of dam construction and power generation are estimated by Agrar-und Hydrotechnik GMBH (AHT) and Howard Humphreys Ltd. (HHL), Kekreti Reservoir Project Feasibility Study (1984), at $114 million. (These costs seem low and probably reflect the procedure the AHT study used to adjust for currency exchange rates. A more realistic cost estimate would be approximately $126 million). Operation and maintenance costs for the dam are estimated to be $25,000 in the first four years of construction and from $217,000 to $220,000 per year subsequently. Operation and maintenance costs for the hydroelectric plant are estimated at $1,140,000 per year starting in year six with the commencement of power generation.

Resettlement. Dam construction and subsequent creation of reservoirs will necessitate the resettlement of the population living in areas that will be flooded. Coode and Partners assume that none of the population will have to be resettled as a result of dam construction at Balingho. Current hydrological estimates indicate that there are few if any villages in the area that will be flooded by Lake Balingho. However, population density in the vicinity of the proposed reservoir is high. We estimate that at least 100,000 people live within a 5 km band along the banks of the river, many of whom depend heavily on swamp rice production to meet food needs. Lake Balingho will flood 11,000 ha of prime swamp rice land, while additional swamp rice land will be lost upstream due to the elimination of tidal action. We conclude that many of these people will find their economic and subsistence bases eroded to the point where they will be forced to move or be resettled.

Without adequate census data and small scale contour maps, we are unable to estimate the population that may have to be resettled because of Lake Balingho. Given the importance of the lands to be flooded, however, we think that resettlement will be a major issue. Because the resettlement of people remains a question, therefore, for purposes of our benefit/cost calculations we assume that the construction of Balingho Dam will not necessitate any resettlement. In a sensitivity analysis (see section 8.5.3.), we include a population of 15,000 to be resettled.

Lake Kekreti will require resettlement. Based on 1983 population estimates, AHT/HHL concludes that approximately 10,600 people will need to be resettled. We estimate resettlement costs at $1,500 per person for a total cost of $16 million. Our resettlement costs are higher than the estimates by AHT/HHL. However, experience with other resettlement projects in Africa indicates that $1,500 per person is a realistic estimate of the costs. It should be noted that these figures will

have to be adjusted for population growth when the year of dam construction is determined. However, for comparative purposes with other studies we have not adjusted for population growth in our benefit/cost analysis. (As discussed in Chapter 6, we speculate that as many as 18,000 people will need resettlement by the time Kekreti Dam is actually constructed.)

Heath impacts. The proposed development actions will have a major impact on public health because of changes in the environment or because of the human population movements they will induce. River basin management actions will result in changes in disease vector habitats and thus the incidence of infectious diseases. The necessary mitigative measures are discussed in the Water-Associated Diseases and Gambia River Basin Development report. These include the establishment of an administrative unit to deal with health problems associated with basin development in general. This will cost $120,000 in the first year of operation and $200,000 annually thereafter. This cost is not considered for any of the individual dam projects, but is included in the combined Balingho Dam and Kekreti Dam project.

Each of the dams will require special health measures to control both schistosomiasis and malaria in the settlements established for construction and servicing of the projects. Costs also will be incurred to control and treat the increased incidence of schistosomiasis among the population living in or near the project and reservoir areas. While malaria incidence will increase among the general population, the disease already is endemic; it is not practical to attribute any additional treatment or control of the incremental cases as a cost to a project. Thus, no costs for malaria control among the general population have been included in the benefit/cost analyses of the two dams.

In the case of Balingho we assume a construction and service population of 2,500. Mitigative health measures will consist of an initial screening of construction and service populations for disease and the control of malaria and schistosomiasis. These costs are estimated at $31,000 in the first year and $17,000 a year from years two through six. For the local population, mitigative health measures will include an annual cost of $50,000 for public health education, a one time cost of $4,800 for the training of public health workers, an annual cost of $11,175 for mollusciciding, and an annual per person cost of $0.09 for antischistosomiasis drugs. We assume that 100,000 persons will be vulnerable to negative health consequences.

In the case of Kekreti we assume a construction and service population of 2,000. Costs for initial screening for disease and control of malaria and

schistosomiasis are estimated at $55,000 in the first year and $16,000 a year from years two through six. For the local population, mitigative health measures include an annual cost of $50,000 for public health education, $11,175 for mollusciciding for incremental cases of schistosomiasis, and an anti-schistosomiasis drug cost of $0.09 per person. We estimate a population at risk of 35,220.

Lost agricultural production. The construction of both Balingho Dam and Kekreti Dam will bring about the flooding and elimination of some existing agricultural production. The importance of this loss is far more critical in the case of Balingho than Kekreti. With the creation of Lake Balingho, a minimum of 11,000 ha of currently cultivated swamp rice will be eliminated due to flooding (as discussed in Chapter 3). Further, we estimate that at least an additional 3,500 ha of swamp rice upstream from the lake will be lost due to the suppression of tidal influence and the attenuation of annual flooding. The higher tidal amplification downstream of the dam will result in the loss of about 600 ha of swamp rice. We estimate that the loss of rice production from Balingho, therefore, will approach 18,000 metric tons a year. (This assumes an average yield of 1.2 MT/ha upstream and 0.8 MT/ha downstream. It also assumes production on the average of the last ten years, although in recent years production has been below average due to lack of rainfall.) Using an economic or shadow import parity price for rice paddy estimated at $181/MT in 1995, we estimate the value of this lost rice at $3.2 million.

The formation of Lake Kekreti also will generate losses in agricultural production. We estimate that 2,200 ha of currently cultivated land will be flooded by the reservoir. Approximately 1,300 tons of maize and 1,600 tons of rice will be lost annually. This has an economic value of $373,000 (assuming an economic import parity price in Senegal Oriental of $181/MT for rice paddy and $233/MT for maize in 1995). Foregone production costs of $100 per ha have been subtracted.

8.3.2. Dam Benefits

The main benefits of Kekreti Dam are hydroelectric power generation and irrigation and of Balingho Dam transportation and salinity control. It is now realized that Balingho Dam alone will not generate much potential for irrigation developmment. As noted previously, we separate the issue of irrigation development from that of dam construction because there will be few if any residual benefits from irrigation to cover any significant portion of the costs of dam construction. For anticipated performance levels in the short-term and medium-term, large-scale irrigation development remains at best a marginal

proposition from a benefit/cost perspective. An economic decision to build any of the proposed dams should be based on nonagricultural benefits.

Transportation. The construction of a bridge across the Gambia river will provide transportation linkages and improved communication between the northern and southern regions of both The Gambia and Senegal. As presently conceived, it will facilitate transportation on the Trans-Gambian Highway, which is the primary communication link between Dakar and Ziguinchor.

Transportation benefits for the Balingho project are taken from Coode and Partners but indexed to 1984 U.S. dollar prices (using the same method explained in section 8.3.1.). Estimated benefits are derived from fees imposed on users of the bridge. The estimated net present value of this benefit is $31 million over 50 years. However, it should be noted that the Coode and Partners estimates of transportation benefits are based on a 1974 study and may now be out of date.

In sum, transportation benefits from Balingho could be significant. From a benefit/cost perspective, nonetheless, the question that must be asked is whether or not most transportation benefits (aside from some river navigation benefits) should be attributable to Balingho Dam when there is the alternative option of constructing only a bridge across the Gambia River.

Hydroelectric power. Estimates of the hydroelectric power benefits for Kekreti Dam are taken directly from the AHT/HHL feasibility study. These benefits have an estimated net present value of $94 million over 50 years. The AHT/HHL study is predicated on the assumption that mining development will take place in Senegal Oriental, which would create a demand for electricity in addition to commercial, residential, and irrigation demand. The benefits thus calculated are based on savings from alternate fossil fuel generation facilities. If mining development does not occur, the benefits assumed by AHT/HHL could be exaggerated. In addition, energy from Manantali Dam in Mali might become available. A careful assessment on a regional level needs to be made of potential energy supply and demand in order not to create excess capacity.

Fishery potential. Regularization of the river flow and the creation of Lake Kekreti and Lake Balingho will have significant impacts on fishery potential. Dam construction, especially at Balingho, will result in changes in habitat, the loss of the salinity gradient, blocking of migration of certain fish species, and elimination of the flow of nutrients downstream into the estuarine and coastal waters. This will result in the creation of a productive reservoir fishery, a slight decrease in marine

finfish production, a decrease in marine shellfish production, a decrease in estuarine fishery production, and a decrease in riverine fishery production. While we have attempted to quantify some of these impacts, it must be noted that because of the complexity of the river ecosystem it is not possible to determine and project in quantitative terms all of the potential consequences. Much is still unknown about the eventual impact on fish production.

Given lake conditions and available food sources, and assuming the necessary management actions, we estimate that the fish catch potential of Lake Kekreti will be 1,400 metric tons a year and of Lake Balingho 5,600 tons a year. In the case of Kekreti this represents almost entirely a net benefit because of the small existing riverine catch. Assuming that it will take ten years to achieve potential catch levels, and subtracting from the potential value the management and production costs, we estimate the annual net value of the potential catch in Lake Kekreti after year ten to be $880,000.

The impacts of Balingho Dam, especially downstream of the dam, are so uncertain that we are not able to quantify and include them in this analysis. Annual losses to existing marine, shellfish, and estuarine fisheries could be devastating, especially for the shrimp and bonga fisheries. A minimum estimate of this loss is $1,400,000 annually. This is offset by the potential catch from Lake Balingho, which after ten years could have an annual gross value of $5,600,000, assuming proper management. Despite the potential of the Lake Balingho fishery, however, it is our opinion that eventually the costs of the negative impacts of Balingho Dam on the riverine, estuarine, and marine fisheries might outweigh the benefit of the lake fishery.

8.3.3. Other Unmeasured Benefits and Costs

The dams will have several types of impacts, both positive and negative, which have yet to be accurately measured and quantified. An important benefit from the creation of the reservoirs is the potential for drawdown agriculture. Experience with large reservoirs in other parts of the developing world suggest that the drawdown areas of Lake Balingho and Lake Kekreti will have significant potential for agricultural and livestock uses. Effective development and management of this land could compensate farmers for the loss of land due to construction and inundation.

Another important benefit is the general stimulation to the economies that the construction and operation of the dams will create, as discussed in Chapter 6.

Construction and service jobs will be created; towns will develop at the dam sites; commerce and agricultural production will be stimulated. The extent and duration of this development activity, however, is uncertain. This benefit will depend on whether OMVG planners develop the forward and backward linkages of these goods and services with the local economies (rather than rely on continued infusion of foreign capital and goods).

Significant improvements in the transportation infrastructure might result from the implementation of one or both dam projects. The amount of people and materials required for these projects will necessitate the expansion and improvement of transportation and communication infrastructures. In addition, both dams together or either individually will improve navigation on the Gambia River.

In general, the dam projects will have what Thayer Scudder calls "multiplier effects" that will constitute unmeasured benefits. These will be more extensive in association with Balingho than with Kekreti and the Guinea projects because of the existing infrastructures in the region of Balingho.

Offsetting these potential positive impacts will be several potentially negative impacts. Foremost among these will be the loss of livestock grazing lands and the production of livestock that depends on them. Clearly the negative impacts on livestock caused by Lake Balingho will be larger than those by Lake Kekreti. Lake Balingho will be larger in surface area, inundate denser vegetation, and affect more dense populations of people and livestock. (The development of the drawdown area might compensate for this loss.)

In addition to the losses in existing agricultural production that have been quantified and included in the benefit/cost analysis, other potential impacts have not been measured. The loss in existing agricultural production, especially due to Balingho, will have far-reaching consequences, perhaps more serious than the numbers indicate. It is well known that women are the primary household food producers and that swamp rice is a major source of family nutrition. The immediate loss of this production with the creation of Lake Balingho will have serious consequences on family nutrition for the affected families and will deprive women of a major asset. Assuming that each woman cultivates a quarter of a hectare, the loss of 15,000 ha of swamp rice will adversely affect upwards of 60,000 women. It is not likely that irrigation expansion will be able to compensate these women, for two reasons. First, we have strong reservations about the potential for rapid expansion assumed in large scale irrigation models. Even under the best of circumstances it

will take a number of years to develop sufficient irrigated area to compensate for the loss of swamp rice production. Second, rights to the use of irrigated land have been given, with the exception of the ongoing experiment at Jahaly Pacharr, to men.

It is unclear from the available documentation on the dams what the downstream impacts will be during the reservoir fillup. This is more of a problem with Kekreti than with Balingho. The AHT/HHL production schedule indicates that the reservoir will be filled in six months, presumably by stopping all water flow. The costs of the impacts of this or any fill up scenario on swamp and recession agriculture, livestock, fisheries, salt water intrusion, and navigation have not been considered. In the final analysis, however, they must be considered both for benefit/cost purposes and for management purposes during the transition period. The implications should be analyzed once more complete water management plans are formulated.

An additional question that construction of Kekreti Dam presents is the effect that the regularization of the river flow for hydroelectric power generation will have on downstream agriculture. Two issues are involved. The first is the effect of the regularization of river flow on existing swamp, tidal, and recession agriculture. Estimates differ on the extent to which annual flooding will be reduced as a result of the construction of Kekreti Dam. In the absence of precise contour maps of areas bordering the river, it is not possible to predict the impacts on agricultural production.

The second issue is the potential for Kekreti Dam alone to control downstream salinity levels and intrusion. Although Kekreti Dam was not originally envisioned with downstream salinity control in mind, the most recent study of HHL indicates that it is possible for Kekreti alone to control saltwater intrusion and still provide sufficient water for irrigation and hydroelectric power generation, as discussed above. This being the case, lands, especially swamp rice areas which have not been cultivated due to water salinity in recent years, could be restored to production during the short and medium terms. In addition, with the regularization of water flow, farmers will have greater certainty about the timing and availability of water. This could contribute significantly to an increase in production levels. While this benefit is not included in our analysis, it obviously is an important consideration.

Loss in forest production will also result with the creation of the lakes. We estimate that 875,900 million cubic meters of timber and 381,700 cubic meters of firewood -- mostly mangrove -- will be lost as a result of construction and flooding

from Balingho Dam; 441,000 million cubic meters of timber and 2,148,000 cubic meters of firewood will be lost from Kekreti Dam. This is a one time loss; it does not represent any continued sustainable yield of wood that might be harvested from the forests if they remained. As the wood currently is not commercially managed, it actually is not appropriate to evaluate either the one time benefit should all the loss be harvested or the long term loss of a sustainable yield. (The Terrestrial Ecology and Gambia River Basin Development report values the mangrove forest to be lost at between $12 million and $18 million in situ and $24 and $36 million market price.) Given the potential of the forests, especially the mangroves, for a sustainable yield, the loss of wood due to inundation should be considered a cost or negative impact of the dams.

The impacts on wildlife in the basin due to dam construction will be minimal if the projects are managed properly. Of far greater importance will be the indirect consequences of the intensification of human activities and consequent impacts on wildlife and wildlife habitat.

8.4. Benefits and Costs of Expanded Irrigation Agriculture

Slow and fast rates for the development of 30,000 ha of irrigated land in The Gambia are proposed by LRDC. Other feasibility studies for OMVG discuss the development of 70,000 ha. However, for the relevant planning period (50 years) we think this somewhat unrealistic. Therefore, in this benefit/cost analysis we use the LRDC model. In addition, we use their slow rate of development, which in our assessment is more realistic. The LRDC slow rate assumes the development of 200 ha per year in years one through three, 300 ha per year in years four through seven, and 600 ha per year in years eight through fifty four. Thus, after 54 years all 30,000 ha will have been developed. Because irrigation projects in the region have not been able to sustain a cropping intensity greater than 120 percent, we decided to calculate internal rates of return using both a cropping intensity of 180 percent, which is commonly assumed in irrigation development models, and 120 percent, which we consider more realistic for the Gambia River Basin.

8.4.1. Irrigation Agriculture Costs

We assume an average investment cost of $10,000/ha for perimeter design and preparation. Production costs for irrigated crops are based on average production costs for rice production used in the irrigation models proposed by LRDC. We

assume a production cost of $325/ha during the wet season and $375/ha during the dry season. We also assume that the user fees included in these costs will cover perimeter operation and maintenance costs.

We additionally estimate that 50 percent of the irrigation expansion will take place on land already being cultivated with swamp rice. (This may be slightly high; our land use analysis indicates that about 43 percent of the land identified by LRDC as being suitable for rice production was under cultivation in 1983.). Thus, the production costs of this area and the value of this lost agricultural production are subtracted from the benefit/cost calculations. We estimate the nonproject production costs to be $12/ha and the yields of rice paddy to be 1 MT/ha.

In addition to the direct costs of irrigation development and production, there also will be costs associated with mitigative health measures (the details are presented in the Water-Associated Diseases and Gambia River Basin Development report). Mitigative health measures consist of the establishment of a health unit for the control of schistosomiasis. Health costs increase with the expansion of irrigated areas. The net present value of mitigative health measures is $220,000.

8.4.2. Irrigation Agriculture Benefits

Production increases in rice are the primary benefit of expanded irrigation. Yield estimates of 4.5 metric tons per hectare in the dry season and 4.0 metric tons per hectare in the wet season are used to calculate expected production levels. (In a sensitivity analysis below, we use a higher yield estimate.) As mentioned above, swamp rice production foregone because of the expansion of irrigation is subtracted.

8.4.3. Unmeasured Benefits and Costs of Irrigation Expansion

If targeted production levels can be reached and maintained, this increase in production could stimualte the development of a variety of commercial activities. Markets for agricultural inputs and outputs would develop as well as a demand for consumer goods. Better transportation, higher incomes, and better nutrition associated with the successful expansion of irrigation activities would stimulate general economic expansion.

On the cautionary side, the expansion of irrigated areas will greatly increase the pest and rodent populations throughout the Gambia River Basin. Agricultural production losses due to insect and animal damage already are significant. Increased losses due to birds, insects, rodent, bush pigs, and, to a limited extent, hippos can be expected.

Nomadic populations and livestock in general may be adversely affected by the expansion of irrigated areas. Irrigated perimeter expansion along the banks of the river, unless properly constructed and managed, will limit the access of nomadic herdsmen and livestock to traditional grazing lands and to the river itself. This could result in serious conflicts between sedentary farmers and nomadic populations.

8.5. Results of the Economic Analyses

To evaluate the benefits and costs of the development projects (from a purely economic perspective), we calculate the internal rates of return as well as the net present values. We also make sensitivity analyses by altering several important fundamental assumptions. We summarize our results here. (Detailed tables and graphs of these economic analyses are presented in GRBS Working Document No. 71.)

8.5.1. Economic Rate of Return for Proposed Development Projects

The economic rates of return for the four development scenarios vary considerably (Table 8.1.).

The economic rate of return for Balingho Dam is low, 1.5 percent. This is due to the substantial costs associated with the loss of 15,000 ha of existing swamp rice production. This loss, of course, actually would vary year by year according to rainfall patterns. Other unmeasured costs not included in this analysis, such as the impact on livestock, might further reduce the economic rate of return.

The economic rate of return for Kekreti Dam is positive, 9.2 percent. Unmeasured benefits, primarily saved agricultural production due to saltwater intrusion management, which have not been included in our analysis, could result in a higher economic rate of return, making Kekreti Dam a more attractive investment. However, two reservations must be made. First, the benefits from hydroelectric power generation may be overestimated, especially if Manantali Dam in Mali should be put into operation and produce a surplus of energy for the region. Second, the construction costs which AHT uses in their economic analysis and which we use here may be low due to the method they use to adjust for shadow currency exchange rates.

The economic rate of return for Balingho Dam and Kekreti Dam combined is 4.8 percent. This low rate of return is due to the negative influence of Balingho Dam. The benefits from Kekreti are not large enough to cover the significant costs associated with Balingho.

Table 8.1.

Economic Rates of Return for Development Projects

Balingo Dam	1.5 %
Kekreti Dam	9.2 %
Balingho Dam and Kekreti Dam Combined	4.8 %
Irrigation Development (Cropping Intensity 180%)	5.9 %
Irrigation Development (Cropping Intensity 120%)	1.1 %

Assumptions: 50 year planning period.
Irrigation separated from dam construction.
Irrigation development of 30,000 ha.

Table 8.2.

Net Present Value for Development Projects

Balingho Dam	-$88,000,000
Kekreti Dam	-$ 7,000,000
Balingho Dam and Kekreti Dam Combined	-$95,000,000
Irrigation Development (Cropping Intensity 180%)	-$12,000,000
Irrigation Development (Cropping Intensity 120%)	-$23,000,000

Assumptions: 10% rate of discount.
50 year planning period.
Irrigation separated from dam construction.
Irrigation development of 30,000 ha.

For irrigation development, the economic rate of return for a cropping intensity of 180 percent is 5.9 percent; for a cropping intensity of 120 percent the return is 1.1 percent. In both cases the base scenario assumes the development of 30,000 ha of irrigated land for rice production over a fifty year period. A cropping intensity of 180 percent represents optimistic assumptions about the incorporation of irrigation into existing farming systems as well as the elimination of existing constraints to intensive agriculture in the basin. A cropping intensity of 120 percent represents more realistic assumptions, given existing conditions.

8.5.2. Net Present Value of Benefits and Costs

The net present value of the four development projects is marginal to negative, assuming a discount rate of 10 percent (Table 8.2.).

The net present value of the Balingho Dam project is -$88,000,000. Assuming a 10% discount rate, we estimate the present value of total costs of Balingho Dam to be $132 million and the value of benefits to be $44 million.

The net present value of the Kekreti Dam project is -$7,000,000. We estimate the present value of total costs of Kekreti Dam to be $105 million and the value of benefits to be $98 million. Improvements in the data base necessary to properly evaluate this option could change these results considerably.

The net present value of Balingho Dam and Kekreti Dam combined is -$95,000,000.

For large scale irrigation development, the net present value for a cropping intensity of 180 percent is -$12,000,000; for a cropping intensity of 120 percent the net present value is -$23,000,000. With 180 percent, the costs have a present value of $71 million and benefits of $59 million. With 120 percent, the costs have a present value of $62 million and benefits of $40 million.

8.5.3. Sensitivity Analysis

Given the uncertainties over important probabilities, we conducted several sensitivity analyses with different assumptions (Table 8.3.). We think it important to assume some resettlement at the Balingho project, so we introduced a resettlement cost stream into our analyses. At the request of OMVG, we also used a discount rate of 6 percent rather than 10 percent for benefit/cost analyses of the dam projects. Finally, also at the request of OMVG, for benefit/cost analyses of irrigation development we used a high yield of 7.5 MT/ha per season rather than

Table 8.3. Sensitivity Analysis

1. Assume resettlement population of 15,000 (rate of discount = 10%)

	IRR	Net Present Value
Balingho Dam	1%	−$105,000,000

2. Assume rate of discount = 6%

	Net Present Value
Balingho Dam	−$77,000,000
Kekreti Dam	$42,000,000
Balingho Dam and Kekreti Dam	−$35,000,000
Irrigation Development	
(Cropping Intensity 180%)	−$ 631,000
(Cropping Intensity 120%)	−$28,000,000

3. Assume a rice paddy yield of 7.5 MT/ha (rate of discount = 10%)

	IRR	Net Present Value
Irrigation Development		
(Cropping Intensity 180%)	20.7%	$35,000,000
(Cropping Intensity 120%)	12.1%	$ 7,000,000

University of Michigan Gambia River Basin Studies, 1985.

4.5 MT/ha and 4.0 MT/ha in the dry and wet seasons respectively. This higher yield is based on the results of the first year of production at Jahaly Pacharr.

As discussed above, we estimate that a minimum of 15,000 persons might need to be resettled because of the Balingho project even though current feasibility studies assume no resettlement will be required. With the costs of this resettlement introduced into the benefit/cost analysis, the internal rate of return for Balingho is 0.97 percent (rather than 1.5 percent). The net present value, assuming a discount rate of 10 percent, is -$105,000,000 (rather than -$88,000,000).

Although at present the World Bank uses a discount rate of 10 to 12 percent, changing economic conditions might result in a lower discount rate in the future. We therefore recalculated the benefit/cost analyses of the dam projects with a discount rate of 6 percent. With this lower discount rate, the net present value of Balingho Dam is -$77,000,000 (rather than -$88,000,000). The net present value of Kekreti Dam is +$42,000,000 (rather than -$7,000,000). The net present value of the two dams combined, therefore, is -$35,000,000 (rather than -$95,000,000). The net present values for irrigation development, assuming the base case yields of 4.5 MT/ha and 4.0 MT/ha, are -$631,000 for a cropping intensity of 180% and -$28,000,000 for a cropping intenstiy of 120%. (The increase in net present value for 120%, compared to use of a discount rate of 10%, is due to the number of years that the net benefit stream is negative.) The internal rate of return does not change because the discount rate is not a variable in its calculation.

Because of optimistic projections based on the results of the first year of production at Jahaly Pacharr, we recalculated the benefit/cost analyses using a yield of 7.5 MT/ha rather than 4.5 MT/ha and 4.0 MT/ha. As might be expected, such a percentage of increase in yield results in significantly higher internal rates of return for irrigation development. With a cropping intensity of 180 percent, the internal rate of return becomes 21 percent (rather than 6 percent) and the net present value +$35,000,000 (rather than -$12,000,000). With a cropping intensity of 120 percent, the internal rate of return becomes 12 percent (rather than 1 percent) and the net present value +$7,000,000 (rather than -$23,000,000). Achieving and maintaining such high yields assumes well managed and maintained irrigation systems, no mechanical breakdowns, and timely input delivery. Existing irrigation systems in the basin have been plagued by failures to achieve and sustain these objectives.

8.6. Guinea Dams

The lack of feasibility studies for the Guinea dams prohibits their inclusion in our quantitative analysis. However, preliminary proposals have identified potential sites and roughly 15,000 ha of irrigable land. While exact costs are not known, we assume that because of the inaccessibility of the present dam sites and irrigable areas the benefit/cost ratios of the Guinean dams will be lower than with Kekreti Dam. With a per hectare development cost of $15,000 (the higher cost figure due to the greater inaccessibility of the Guinean dams), the total costs associated with irrigation expansion in Guinea will be $225 million. Health mitigative measures associated with construction of the three dams will be $79,000 in year one and $19,000 a year to completion. No estimates are available on the health costs for the indigenous populations. In addition, due to construction and flooding the Guinea dams could result in the loss of roughly 9,300 cubic meters of timber and 577,000 cubic meters of firewood. The reservoirs of the Guinea Dams, however, will generate a potential fish catch of 476 metric tons a year. These fisheries would produce an economic value of $274,000 annually.

9. FURTHER CONSIDERATIONS

Development of the Gambia River Basin is essential to the people of the basin, especially in the face of uncertain rainfall and expected population growth. Basin development furthermore is necessary for the Member States to achieve greater food security. Given the limited resources available to basin planners, however, careful consideration must be given to development options and to defining objectives.

In our studies we have analyzed the impacts of proposed development projects on a number of important environmental and socioeconomic variables or attributes. The OMVG staff and Member State planners now must evaluate the probability that the attributes will be affected in the direction and to the degree we suggest. Where we have been unable to assess impacts on attributes, they must conduct further studies. Furthermore, and as important, the Member State decision makers must weight the importance of the impacts we analyze. These evaluations are necessary before final development decisions can be made. Evaluation is the prerogative of the decision makers themselves rather than of those who investigate the potential impacts of the projects.

Of necessity, we have focused on impacts more relevant to some basic development objectives than to others. Our studies did not systematically consider the objective of promoting industrial development, although that is assumed to be a consequence of building the dams and investing in irrigation agriculture. Nor did we directly consider the objective of increasing per capita income, except insofar as rural per capita income is an important attribute in the assessment of irrigation projects.

We did consider in some detail, however, many attributes relevant to the objective of enhancing the quality of life. This was the charge of our public health study and a significant component of our socioeconomic study. Although effective basinwide development on the whole should enhance the quality of life of the basin populations, it will have a mixed impact on many aspects of their lives. For example, as irrigation agriculture is developed, the role of the farmer in perimeter management will be an indicator of the quality of life of his household. Resettlement policies will have a significant effect on the quality of life. Public health impacts will have many positive as well as negative characteristics. Given their definitions of quality of life, basin planners should be able to evaluate the

proposed development projects in terms of the probabilities that the projects will enhance the quality of life of the population.

We extensively considered many attributes essential to maintaining environmental quality in the basin. This was the primary charge of both our aquatic ecology and terrestrial ecology studies. That basinwide development often comes at the expense of environmental quality is to be expected, although some aspects of the environment can be improved or at least preserved through careful planning and management of development projects. Our assessment of potential impacts should be placed in the context of basinwide development. When we discuss impacts on endangered species, such as on the manatee and the sitatunga, for example, this should not suggest that we necessarily endorse their preservation at the expense of important basin development projects. When we discuss the importance of the mangroves, we do so in terms of their contributions to the production of the fisheries as well as to the ecology of the river. In the final analysis, any trade-offs that must be made between preserving environmental quality and enhancing quality of life are for decision makers to make. Our conclusions should enable them to do so with more certainty than they might have been able to do so before.

Finally, we have analyzed the impacts of development projects on attributes important to the objectives of improving national balances of payments and achieving food security. We especially urge OMVG and Member State planners to give further consideration to these objectives. In the context of achieving greater self-sufficiency, they may be forced to make trade-offs between improving national balances of payments and achieving food security and even between increasing per capita income and promoting industrial development.

The implications of the development projects for improving the national balances of payments are uncertain. In regards to the Kekreti project, the potential investment in Kekreti is primarily justified on the assumption that its hydroelectric power generation will permit mining activity in Senegal Oriental. If these benefits do not ensue, the economic justification for Kekreti is questionable. However, Kekreti -- or some water control project -- still will be required to expand irrigation agriculture significantly, even if this involves a trade-off with the balance of payments. In regards to the Balingho project, its justification of control of the salt tongue and development of irrigation agriculture unquestionably involves a trade-off with improving the national balance of payments. (The bridge component -- or a bridge alone -- is altogether another matter in this regard.)

The fundamental trade-off, however, seems to be between achieving food self-sufficiency and improving national balances of payments. Our analysis of the current and proposed irrigation projects leads us to conclude that it is less expensive to import food and rice at current world prices into the urban areas than to produce it in the countryside for urban consumption at current costs of production. The Member States may allocate scarce foreign exchange inefficiently if they pursue the objective of attaining food security through irrigation when they do not have a comparative economic advantage in the production of rice. A country has a comparative advantage in production if a return is realized when the land, labor, capital, and water resources used are priced at their opportunity costs. If a country uses more domestic resources to produce a crop than it would use to earn foreign exchange to import that food, then it is pursuing agricultural objectives at the expense of its national balance of payments. Nonetheless, in the eyes of a nation, the stability of being able to rely on domestic production may be worth the price.

If the decision is made to invest in large-scale development of irrigation agriculture, the costs of irrigation ultimately should be sustainable and willingly incurred by either the development authorities or the farmers themselves. That is, the costs should either be surpassed by returns from agriculture or be subsidized in part by other productive sectors of the national economy. In the long run, achieving food security requires a strategy of phasing out donor participation and employing only indigenous national resources.

Our analyses suggest that major expansion of large-scale irrigation in the near term, as called for in Gambia River Basin development plans, appears premature. Improvement of performance levels on existing schemes to viable levels as well as removal of constraints which limit increases in production of both irrigated and rainfed crops should be the preconditions for further expansion. Irrigated agriculture is unlikely to make a significant contribution to domestic food supply or alleviate foreign exchange problems for a number of years. In the interim, efforts should continue to be made to improve productivity of rainfed crops, including swamp rice, which offer the best prospects for improvement in the short and medium terms.

Member State decision makers therefore should reconsider whether or not capital-intensive large-scale irrigation schemes alone will be successful. In essence, this is a single development strategy that will encumber scarce resources that could be used to increase productivity in other agricultural sectors. Investment in the

technology, facilities, and infrastructure required for large-scale projects may prevent the development of technologies, facilities, and infrastructure appropriate for small-scale irrigation perimeters, improvement of rainfed agriculture, and diversification of agricultural production. These trade-offs remain to be investigated.

In fact, many constraints might impede successful implementation of large-scale irrigation agriculture. Farmers may be reluctant to accept the risks inherent in irrigation agriculture. Double-cropping might not be achieved. Alternative land use will be foregone. Decision makers must ascertain the probability that these constraints can be overcome efficiently without serious drains on available resources.

Decision makers therefore might consider a diverse portfolio of investment in agriculture in order to pursue food security with an optimal strategy. For the short-term to medium-term, it would be advisable to adopt a strategy based on low capital investment to minimize debt service charges. Such a strategy would emphasize improvement in rainfed agriculture as well as development of small-scale irrigation perimeters with some degree of water control insured. This would assume an evolution into large-scale irrigation schemes as techniques and infrastructures become more reliable and capital more available than they are now. While increases in productivity theoretically might not be as high as envisioned for large-scale irrigation agriculture, production would be more reliable with less need for initial investment and less need for continued government subsidy.

Large scale irrigation is proposed as a solution in the face of declining rainfall in the basin. The issue, however, is not declining rainfall, although that is a factor. The issue is declining rural per capita productivity. Declining productivity is a function of ineffective agricultural policy and management as well as of declining rainfall and other natural factors. Declining productivity can be attributed in part to lack of incentive to produce, lack of markets and input supply structures, and rural exodus.

In sum, insofar as agriculture is concerned, if the issue is one of lack of rainfall, then development of water resources in the river basin to permit large-scale irrigation might be ideal. However, if the issue is one of lack of productivity, then river basin development involves more than management of water resources for irrigation purposes. A coordinated strategy that considers the trade-offs among all basic Gambia River Basin development objectives should be pursued.

Finally, insofar as the basic objectives of these Gambia River Basin studies are concerned, our analyses suggest that the linkage of the Balingho project with the Kekreti project should be reevaluated. By itself, Kekreti could be a viable project economically, entailing acceptable environmental impacts and risks. Furthermore, any upper basin dam and reservoir would be extremely important for the development of irrigation agriculture, especially in The Gambia.

Balingho Dam, however, at present does not seem economically or environmentally viable. The issues with regard to Balingho involve considerable uncertainty and therefore require further investigation. Firm estimates of the loss of rice production that the project will incur require small-scale contour maps that are not yet available. Resettlement of some of the population along the river is a probability, but whether or not that will be a serious problem depends on the loss of rice production as well as precise information on upland land use. The full extent of the impacts of the dam on the marine and estuarine fisheries remains to be determined. As the Gambia river is the heart of The Gambia, the risks associated with the impacts of Balingho Dam suggest that OMVG would be wise to reconsider its construction in tandem with Kekreti Dam.

Member State decision makers, therefore, should consider scheduling the construction of Balingho Dam after rather than before Kekreti Dam. Balingho Dam might have extremely serious and irreversible environmental and even economic consequences. Such is not the case with Kekreti, especially in view of simulations of the autonomous operation of Kekreti Dam. Construction of Kekreti Dam first would allow OMVG to pursue important development objectives while continuing to investigate the viability of Balingho Dam. Balingho Dam in the long term might prove to be economically feasible, although the alternative of a bridge to provide urgently needed transportation across the river could be considered. In the short term, the probable environmental and economic consequences of Balingho seem not to be worth the risk.

On the assumption that the energy benefits are plausible, planning for the Kekreti project should proceed. Even if the energy benefits were to be less than anticipated, plans should be made for some project in the upper basin to manage the water resources throughout the basin. There seem to be no serious environmental obstacles to implementation of the Kekreti project; it would benefit both Senegal and The Gambia. Planning for the Guinea dams should proceed to the point of feasibility studies for one or several. Planning for the Balingho project, however,

should be revised to seriously entertain the possibility of its delay until well after Kekreti Dam is constructed. Balingho should be delayed at least until any loss in agricultural production it would incur would be offset by gains in agricultural production realized from Kekreti. During this period, our analysis of the Balingho project could be reevaluated.

BIBLIOGRAPHY/BIBLIOGRAPHIE

ACARR Working Party on Fishing Effort and Monitoring of Fish Stock Abundance. 1976. "Monitoring of fish stock abundance: the use of catch and effort data," FAO Fisheries Technical Paper No. 155, FIRS/T155, 101 p.

Ackermann, W.C.; White, G.F. and Worthington, E.B., editors. 1973. Man-made Lakes: Their Problems and Environmental Effects, Monograph 17. America Geophysical Union, Washington, D.C.

Agrar-und Hydrotechnik GMBH and Howard Humphreys, Ltd. 1984. Kekreti Reservoir Feasibility Study, Main Report and Annex A-I.

Albaret, J. J. and Gerlotto, F. 1976. "Biologie de l'ethmalose (Ethmalosa fimbriata Bowdich) en Cote D'Ivoire, I: Description de la reproduction et des premiers stades larvaires," Doc. Scient. Centre Rech. Oceanogr (Abidjan), 7(1), July 1976, p. 113-133.

Alverson, D.L., editor. 1971. "Manual of methods for fisheries resource survey and appraisal, Part I: Survey and charting of fisheries resources," FAO Fisheries Technical Paper No. 102, FIRM/T102, 80 p.

American Fisheries Society. 1967. "Reservoir fishery resources symposium," American Fisheries Society, Washington, D.C., 569 p.

American Society of Planning Officials. 1973. "Land use and the environment," Virginia Curtis, editor. Environmental Protection Agency, Office of Research and Monitoring, Environmental Studies Division, Washington, D.C., 200 p.

Anderson, K.P. 1965. "Manual of sampling and statistical methods for fisheries biology, Part 2: statistical methods chapter No. 5: computations," FAO Fisheries Technical Paper No. 26, FIb/T26 Suppl. 1, 25 p.

Anonymous. 1961. "Bilharziasis/schistosomiasis," Phoenix, 1(3), p. 1-16.

Ardill, J.D. and Thompson, R.K. 1975. "The freshwater prawn (Macrobrachium rosenbergii) in Mauritius," FAO/CIFA Symposium on Aquaculture in Africa (Accra: Sept. 30-Oct. 6), CIFA/75/SE 4, 13 p.

Arid Lands Information Center. 1983. Environmental Profile of Guinea (Draft), Robert Varady, compiler. Office of Arid Lands Studies, University of Arizona, Tucson, Arizona, 1980. December 1983.

Arid Lands Information Center. Environmental Profile of The Gambia (Draft). Office of Arid Lands Studies, University of Arizona, Tucson, Arizona, October 1980.

Arid Lands Information Center. 1980. Environmental Profile of Senegal (Draft). Office of Arid Land Studies, University of Arizona, Tucson, Arizona, September 1980.

Arnstein, S. and Chirstakis, A., editors. 1975. Perspectives on Technology Assessment. Science and Technology Publishers, Jerusalem.

Aubray, R. 1975. "The fishery of Gambia," FAO Department of Fisheries, WS/H2178, 8 p.

AVM Instrument Company. 1979. AVM Radiotelemetry Equipment and Techniques Manual. Champaign, Illinois, 32 p.

Backiel, T. and Welcomme, R.L., editors. 1980. "Guideline for sampling fish in inland waters," FAO/EIFAC Technical Paper No. 33, EIFAC/T33, 176 p.

Balayut, E.A. 1983. "Stocking and introduction of fish in lakes and reservoirs in the ASEAN (Association of South Asian Nations) Countries," FAO Fisheries Technical Paper 236, FIRI/T236, 82 p.

Balon, E.K. and Coche, A.G., editors. 1974. Lake Kariba: A Man-made Tropical Ecosystem in Central Africa. Dr. W. Junk Publishers, The Hague, 767 p.

Bazigos, G.P. 1973. "Deck sampling; A pilot trawling survey at Lake Malawi," FAO Promotion Integrated Fishery Development Project. UNDP/SF/MLW. 16, February 1973, S.E./2, 39 p.

Bazigos, G.P. 1974. "Applied fishery statistics," FAO Fisheries Technical Paper No. 135, FIPS/T135, 164 p.

Bazigos, G.P. 1975. "The statistical efficiency of echo surveys with special reference to Lake Tanganyika," FAO Fisheries Technical Paper. No. 139, FIPS/T139, 52 p.

Bazigos, G.P. 1983. "Applied fishery statistics," FAO Fisheries Technical Paper No. 135, FIPS/T135, 164 p.

Bazigos, G.P. 1983. "Design of fisheries statistical surveys on inland waters," FAO Fisheries Technical Paper No. 133, FIPS/T133, 122 p.

Bazigos, G.P. 1983. "Mathematics for fishery statisticians," FAO Fisheries Technical Paper No. 169, FIPS/T169, 183 p.

Beanlands, Gordon E. and Duinder, Peter N. 1981. "An Ecological Framework for Environmental Impact Assessment In Canada." Dalhousie University, Institute for Resource and Environmental Studies.

Beddington, J.R. and Rettig, R.B. 1983. "Approaches to the regulation of fishing effort," FAO Fisheries Technical Paper No. 243, FIPP/FIRM/T243, 39 p.

Benedetti-Crouzet, E.; Dussart, B. et al. 1979. Les Retenues d'Eau: Creation, Evolution, Impacts, Surveillance. Synthese bibliographique, Agence Financière de Bassin. Seine-Normandie [and] I.B.D. Sarlat [France], 258 p.

Berkowitz, D.A. and Squires, A.M., editors. 1971. Power Generation and Environmental Changes. MIT Press, Cambridge, Massachusetts, 440 p.

Bernacsek, G.M. 1984. "Dam design and operation to optimize fish production in impounded river basins, based on a review of the ecological effects of large dams in Africa," CIFA Technical Paper No. 11. Food and Agriculture Organization, Rome.

Bernard, K.J. and Deom, J. 1975. "Water resources development and public health: a bibliography," MPD/75.4, World Health Organization, Geneva, 43 p.

Bernhard, M. 1976. "Manual of methods in aquatic environment research, Part 3: sampling and analysis of biological material," FAO Fisheries Technical Paper No. 158, FIRI/T158, 124 p.

Bhukaswan, T. 1980. "Management of Asian reservoir fisheries," FAO Fisheries Technical Paper No. 207, FIRI/T207, 69 p.

Bisset, Roland. 1978. "Quantification, decision-making and environmental impact assessment in the United Kingdom," Project Appraisal for Development Control, Department of Geography, University of Aberdeen. Academic Press, London, 1978.

Bisset, Ronald. 1980. "Methods for Environmental Impact Analysis: Recent Trends and Future Prospects," Project Appraisal for Development Control, Department of Geography, University of Aberdeen, U.K. Academic Press, London, 1980.

Biswas, S. 1966. "Ecological studies of phytoplankton in the newly forming Volta Lake of Ghana," Journal of the West African Science Association, 11 (1 and 2), p. 13-19.

Biswas, S. 1969. "The Volta Lake: some ecological observations on the phytoplankton," Verh. Internat. Verein. Limnol. 17, p. 259-272.

Boto, G., and Wellington, J.T. 1983. "Phosphorus and nitrogen nutritional status of a northern Australian mangrove forest," Marine Ecology Progress Series, 11, p. 63-69.

Brabant, J.C. and Nedelec, C. 1983. "Bottom trawls for small-scale fishing: adaption for pair trawling," FAO Fisheries Technical Paper No. 189, FIIT/T189 (suppl. 1), 42 p.

Brander, K. 1975. "Guidelines for collection and compilation of fishery statistics," FAO Technical Paper No. 148, FIRS/T148, 46 p.

Brewer, R. 1979. Principles of ecology. W.B. Saunders, Philadelphia, 299 p.

Bromley, D.W. et al. 1970. "Procedures for Evaluation of Water and Related Land Resources Projects." Center for Resource Policy Studies and Programs, University of Wisconsin, Madison, WI.

Bromley, D.W.; Schmid, A.A. and Lord, W.B. 1971. "Public water resource project planning and evaluation," Working Paper No. 1, Center for Resource Policy Studies and Programs, University of Wisconsin, Madison, WI.

Brown, Curtis A. 1984. "The Central Arizona water control study: a case for mulitobjective planning and public involvement," Water Resources Bulletin, 20 (3) June 1984.

Burczynski, J. 1982. "Introduction to the use of sonar systems for estimating fish biomass," FAO Fisheries Technical Paper No. 191 Revision 1, FIRM/T191, 89 p.

Burnet, A.M.R. 1967. "Electric fishing equipment design notes," New Zealand Marine Department Fisheries Technical Report No. 19, 48 p.

Burnet, A.M.R. and Wallace, D.A. 1973. "The relation between primary productivity, nutrients, and the trout environment in some New Zealand lakes," New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Bulletin No. 10, 27 p.

Buskirk, Eli Drannon, Jr. 1976. "Economic impact analysis of reservoir and riverine fisheries in the Mekong River Basin of Northeast Thailand," Mekong Basinwide Fishery Studies Working Document No. 30, School of Natural Resources, University of Michigan, Ann Arbor, Michigan, 180 p.

Buskirk, Eli Drannon. 1976. Economic Impact Analysis of Reservoir and Riverine Fisheries in the Mekong River Basin of Northeast Thailand. The University of Michigan, Ann Arbor (University Microfilm).

Caddy, J.F., editor. 1982. "Provisional world list of computer programmes for fish stock assessment and their availability by country and fisheries institutes," FAO Fisheries Circular No. 746, FIRM/C746, 51 p.

Caddy, J.F., editor. 1983. "Advances in assessment of world cephalopod resources," FAO Fisheries Technical Paper 231, FIRM/T231, 452 p.

Caisse Centrale de Cooperation Economique. "Evaluation Economique de l'Aménagement de la Rive Gauche du Fleuve Sénégal, Annexes," Ministere des Relations Extérieures, Cooperation et Development, Paris, Decembre 1982.

Caisse Centrale de Cooperation Economique. 1982. "Evaluation Economique de l'Aménagement de la Rive Gauche du Fleuve Sénégal, Rapport Général." Ministere des Relations Extérieures, Cooperation et Development, Paris, Decembre 1982.

Carpenter, R.A. 1981. "Balancing economic and environmental objectives: the question is still, how?" Environmental Impact Assessment Review, 2(2), 1981.

Carr, A. 1982. "Tropical forest conservation and estuarine ecology," Biological Conservation, 23, p. 247-259.

Carr, A. 1976. "The blitz is on to save the sea cow," International Wildlife, 6(2), p. 12-25.

Chakroff, M.S. 1981. "Aquaculture extension services case studies," FAO Fisheries Circular No. 740, FIRI/C740, 27 p.

Chen, K.; Lagler, K.F. et al. 1974. Growth Policy: Population, Environment, and Beyond, The University of Michigan Press, Ann Arbor, Michigan.

Chen, K.; Mathes, J.C.; Jarboe, K.; and Wolfe, J. 1979. "Value oriented social decision analysis: enhancing mutual understanding to resolve public policy issues," IEEE Transactions on Systems, Man, and Cybernetics, (9), September, 1979).

Chen, K.; Mathes, J.C. and Jarboe, K.P. 1980. "Clarifying Energy Debates: Preliminary Results of a Social Decision Analysis," Proceedings of the International Conference on Cybernetics and Society (October 8-10, 1980), IEEE, New York.

Chen, K.; Mathes, J.C.; Jarboe, K.P. and Solberg, S. 1981. "Alternative Energy Futures: Interest Group Trade-offs," Proceedings of the International Conference on Cybernetics and Society (October 26-28, 1981) IEEE, New York.

Chimits, P. 1957. "The tilapias and their culture, a second review and bibliography," FAO Fisheries Bulletin, 10 (1), p. 1-24.

Christie W.J. 1978. "A study of freshwater fishery regulation," FAO Technical Paper No. 180, FIRI/T180, 46 p.

Clark, R.D., Jr. and Lackey, R.L. 1975. "Computer-implemented simulation as a planning aid for state fisheries management agencies," Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, FWS-3-75, 179 p.

Clark, R.D., Jr. and Lackey, R.T. 1976. "A technique for improving decision analysis in fisheries and wildlife management," Virginia Journal of Science, 27(4), p. 199-201.

Coche, A.G. 1971. "Lake Kariba Basin: a multidisciplinary bibliography, annotated and indexed 1954-1968," Fisheries Research Bulletin, Zambia, 5, pp. 11-87.

Coche, A.G. 1982. "Aquaculture in fresh water, a list of reference books 1953-1981," FAO Fisheries Circular No. 724 Revision 1, FIRI/C724, 19 p.

Coche, A.G. 1983. "The cultivation of fish in cages, an indexed bibliography 1965-1983," FAO Fisheries Circular No. 714, Revision 1, FIRI/C714, 61 p.

Coche, G. 1982. "Aquaculture in marine waters: a list of reference books, 1961-1981," FAO Fisheries Circular No. 723, Revision 1, FIRI/C723, 18 p.

Coche, G. 1982. "Coastal aquaculture: development perspectives in Africa and case studies from other regions," FAO/CIFA Technical Paper No. 9, CIFA/CPCA/T9, 259 p.

Commission OMVG/Guinée. 1985. "Observations relatives aux études socio-economiques et d'environement éffectuées par l'USAID/Université de Michigan dans le cadre de l'OMVG, mimeo, 3 p.

Conant, F.; Rogers, P. et al. 1983. "Resource inventory and baseline study methods for developing countries," American Association for the Advancement of Science, Washington, D.C., 1983.

Coode and Partners. 1974. The Gambia Barrage Estuary Study, Vol. 1, 2.

Cooper, Charles F. 1968. "Ecosystem Models in Watershed Management," Annual Meeting of American Society of Range Management, Albuquerque, New Mexico, February 14, 1968, mimeo.

Cuinat, R. and Dumas, J. 1975. "Ecological diagnosis in salmonid streams," FAO/EIFAC Technical Paper No. 22, EIFAC/T27, 133 p.

Danish Hydraulic Institute. 1982. "Studies of the Effect of a Barrage on Sedimentation."

Dasmann, R.F.; Milton, J.P. and Freeman, P.H. 1973. Ecological Principles for Economic Development. Weber, London.

Davies, B.R.; Hall, A. and Jackson, P.B.N. 1975. "Some ecological aspects of the Cabora Bassa dam," Biological Conservation, 8, p. '89-201.

Dee, N. and Baker, J. et al. 1973. "An environmental evaluation system for water resources planning."

Delogu, O.E. 1974. "United States experiences with the preparation and analysis of environmental impact statements: The National Environment Policy Act," IUCN Environmental Policy and Law Paper, International Union of Nature and Natural Resources, Morges, Switzerland, 1974.

Deom, J. 1975. "Water resources development and health: A selected bibliography," World Health Organization, MPD/76.6, 68 p.

Dill, W. A., editor. 1972. "Report of the symposium on the major communicable fish diseases in Europe and their control," FAO/EIFAC Technical Paper No. 17, EIFAC/T17, 40 p.

Dill, W.A. 1959. "A pro forma for a river basin development survey (of dams, diversions, reservoirs, etc.) with respect to fisheries," FAO Fisheries Division, Biology Branch, FB/59/T5, 12 p.

Dill, W.A., editor. 1973. "Symposium on the major communicable fish diseases in Europe and their control: Panel reviews and relevant papers," EIFAC Technical Paper No. 17, Supplement 2, EIFAC/T17, 255 p.

EIFAC Working Party on Water Quality Criteria for European Freshwater Fish. 1976. "Report on copper and freshwater fish," FAO/EIFAC Technical Paper, No. 27, EIFAC/T27, 21 p.

EIFAC Working Party on Water Quality Criteria for European Freshwater Fish. 1980. "Report on combined effects of freshwater fish and other aquatic life of mixtures of toxicants in water," FAO/EIFAC Technical Paper No. 37, EIFAC/T37, 49 p.

EIFAC Working Party on Water Quality Criteria for European Freshwater Fish. 1983. "Report on chromium and freshwater fish," FAO/EIFAC Technical Paper No. 43, EIFAC/T43, 31 p.

ESSA (Environmental and Social Systems Analysts, Ltd.) 1982. "Review and evaluation of adaptive environmental assessment management," Environment Canada, Ottawa, Ontario, 21-36/1983E, 116 p.

Eddie, G.C. 1983. "Support and development of the retail trade in perishable fishery products," FAO Fisheries Technical Paper No. 235, FIIU/T235, 53 p.

Edgcomb, G., compiler. 1965. "Man-made lakes: A selected guide to the literature," National Academy of Sciences/National Research Council, Washington, D.C., 98 p.

Eicher, C. and Baker, D. 1982. "Research on Agricultural Development," MSU International Development Paper No. 1. Lansing: Michigan State University, Lansing, Michigan.

Elliott, M.L. 1981. "Pulling the pieces together: amalgamation in environmental impact assessment," Environmental Impact Assessment Review, 2(1), p. 11-38.

Environmental Research Institute of Michigan. 1980. "Seminar on remote sensing applications and technology transfer for international development," Environmental Research Research Institute of Michigan, Ann Arbor, Michigan, 85 p.

Estes, T.S., editor. 1975. "Proceedings of the seminar-workshop on artisan fisheries development and aquaculture in Central America and Panama," University of Rhode Island, International Center for Marine Resource Development, Kingston, 182 p.

Everhart, W.H.; Eipper, A.W. and Youngs, W.D. 1975. "Principles of fishery science," Cornell University Press, Ithaca, NY, 288 p.

FAO, 1977. "Fishery country profile: The Gambia," FID/CP/GAM Rev.1., p. 4. (In Spanish).

FAO, 1977. "Report on the artisanal fisheries development and training mission to Nigeria, Benin, Ghana, and The Gambia, January/February 1975," Norwegian Funds In Trust, FAO/TF/RAF 80, 61 p.

FAO, 1978. "Models for fish stock assessment," FAO Fisheries Circular No. 701, FIRM/C701, 122 p.

FAO, 1978. "Some scientific problems of multispecies fisheries," Expert Consultation on Management of Multispecies Fisheries, 1977 Sept. 20-23, Rome, FAO Fisheries Technical Paper No. 181, FIRM/T181, 42 p.

FAO, 1979. "Role of fishery technology in management and development of freshwater fisheries in Africa," FAO/CIFA Technical Paper No. 6, Fisheries Department, CIFA/T6, 67 p.

FAO, 1980. "Comparative studies on freshwater fisheries," FAO Fisheries Technical Paper No. 198, FIR/T198, 46 p.

FAO, 1980. "The collection catch and effort statistics," FAO Fisheries Circular No. 730, FIRM/C730, 63 p.

FAO, 1981. "Conservation of the genetic resources of fish: problems and recommendations," Report of the Expert Consultation on the Genetic Resources of Fish, Rome, 9-13 June 1980, FAO Fisheries Technical Paper No. 217, FIRI/T217, 43 p.

FAO, 1981. "Methods of collecting and analysing size and age data for fish stock assessment," FAO Fisheries Circular No. 736, FIRM/C736, 100 p.

FAO, 1981. "Report of the working party on the promotion of fishery resources research in developing countries," Advisory Committee of Experts on Marine Resources Research (ACMARR), FAO Fisheries Report No. 251, FIRD/R251, 235 p.

FAO, 1983. "Selected list of FAO publications on fishery resource appraisal methodology," FAO, Rome, 4 p.

FAO, 1970. "Report of the man-made lakes stock assessment working Group, Jinja, Uganda, 11-16 May 1970," FAO Fisheries Reports, No. 87, FIRD/R87, 12 p.

FAO/ACMARR/IAVOI976. "Indices for measuring responses of aquatic ecological systems to various human influences," Working Party on Ecological Indices of Stress to Fishery Resources, FAO Fisheries Technical Paper No. 151, FIR/T151, 66 p.

FAO/CIFA, 1976. "Symposium on Aquaculture in Africa," FAO/CIFA Technical Paper No. 4, Supplement 1, CIFA/T4, 791 p.

FAO/EIFAC 1978. "The value and limitations of various approaches to the monitoring of water quality for freshwater fish," Working Party on Biological Monitoring, FAO/EIFAC Technical Paper No. 32, EIFAC/T32, 27 p.

FAO/EIFAC. 1974. "Report of the symposium on methodology for the survey, monitoring and appraisal of fishery resources in lakes and large rivers," FAO/EIFAC Technical Paper No. 23, EIFAC/T23, 33 p.

FAO/EIFAC. 1982. "Report of the symposium on stock enhancement in the management of freshwater fisheries," EIFAC Technical Paper No. 42, EIFAC/T42, 43 p.

FAO/SIDA. 1983. "Manual of methods in aquatic environment research, part 9: analyses of metals and organochlorines in fish," FAO Technical Paper No. 212. 33 p. (Also available in French as "Manual des méthodes de recherche sur l'environnement aquatique neuvieme partie")

FAO/UNDP. 1975. "Lake Nasser Development Centre, Egypt: project findings and recommendations," FI:DP/EGY/66/558 Terminal Report.

FAO/UNDP. 1975. "First Regional Workshop on Aquaculture Planning in Africa, Accra, 1975," FAO/UNDP Aquaculture Development and Coordination Programme, ADCP/REP/75/1, 114 p.

FAO/UNDP. 1975. "Kanji Lake Research Project, Nigeria: project findings and recommendations," FAO FI:DP/NIR/66/524 Terminal Report, 87 p.

Farvar, M.T. and Milton, J.P. editors. 1972. Careless Technology: Ecology and International Development, Natural History Press. Holdgate, M.W. and White, G.F. 1977. Environmental Issues, Scope report no. 10, John Wiley & Sons.

Fraser, J.C. 1972. "Water levels, fluctuation, and minimum pools in reservoirs for fish and other aquatic resources: an annotated bibliography," FAO Fisheries Technical Paper No. 113, FIRI/T113, 42 p.

Fraser, J.C. 1975. "Determining discharges for fluvial resources," FAO Fisheries Technical Paper No. 143, FIRS/T143, 102 p.

Freeman, P.H. 1977. Large Dams and the Environment. International Institute for Environmenta and Development, 108 p.

Funk, J.L. and Robinson, J.W. 1974. "Changes in the channel of the lower Missouri River and effects on fish and wildlife," Aquatic Series No. 11, Missouri Department of Conservation, 52 p.

Garcia, S. and LesReste, L. 1981. "Cycles vitaux, dynamique, exploitation et aménagement des stocks de crevettes penaéides côtières," FAO Document Technique sur les Peches No. 203, FIRM/T203, 210 p.

Garner, J. 1962. "How to make and set nets or the technology of netting," Fishing News (Books) Ltd., London, 95 p.

Gasaway, C. R. 1970. "Changes in the fish population in Lake Francis Case in South Dakota in th first 16 years of impoundment," Technical Papers of the U.S. Bureau of Sport Fisheries and Wildlife, 56, 30 p.

Gaudet, J.L., editor. 1981. "Report of the technical consultation on the allocation of fishery resources, Vichy, France, 21-23 April 1980," FAO/EIFAC Technical Paper No. 38, EIFAC/T38, 45 p.

Gerlotto, F. 1976. "Biologie de Ethmalosa fimbriata (Bowdich) en Côte d'Ivoire II. -- Etude de la croissance en lagune par la methode de Peterson," Doc. Scient., Centre Rech. Oceanographique Abidjan, 7(2), December 1976, 27 p.

Getz, L.L.; Prather, P.C. and Platt, H.M. 1975. "Schistosomiasis in South America, I: Current status in Brazil," The Biologist, 57 (4), p. 143-165.

Gittinger, J.P. 1982. Economic Analysis of Agricultural Projects. The Johns Hopkins University Press, Baltimore.

Golubeu, G.N. and Biswas, A.K. 1979. Interregional Water Transfers, Problems and Prospects. Pergamon Press.

Gorman, O.T. and Karr, J. R. 1978. "Habitat structure and stream fish communities," Ecology, 59 (3), p. 507-515.

Grover, J. H., editor. 1981. Allocation of fishery resources. FAO, Rome, 623 p.

Grover, J.H., ed. 1980. "Allocation of fishery resources," Proceedings of the Technical Consultation on Allocation of Fishery Resources held in Vichy, France, 20-23 April 1980, FAO/American Fisheries Society.

Gulland, J.A. 1966. "Manual of sampling and statistical methods for fisheries biology," FAO Manuals in Fisheries Science No. 3, FRS/M3, 92 p.

Gulland, J.A. 1977. "Buts et objectifs de l'aménagement des pêches," FAO Documents techniques surs les pêches, No. 166, FIRS/T166, 15 p.

Gulland, J.A. 1980. "Some problems of the management of shared stocks," FAO Fisheries Technical Paper No. 206, FIRM/T206, 22 p.

Gulley, F.B. and Medina, E. 1975. Tropical Ecological Systems. Springer-Verlag, NY.

Hagan, R.M. and Roberts, E.B. 1973. "Ecological impacts of water storage and diversion projects," in Environmental Quality and Water Management, Goldman, C.R. McCoy; J. and Richardson, P.J., editors, W.H. Freeman, San Francisco, CA, p. 196-215.

Hall, G.E., editor. 1971. "Reservoir fisheries and limnology," American Fisheries Society, Special Publication No. 9, Washington, D.C., 511 p.

Hamilton, L.S. and Snedeker, S.C. 1984. Handbook for Mangrove Area Management. East-West Center, Honolulu, Hawaii.

Hansen, A.J. 1978. "Case Studies Environmental Assessment of Foreign Donor Supported Projects in Indonesia," Environmental and Policy Institute, East-West Center, Honolulu, Hawaii.

Harza Engineering Company. 1980. Environmental Design Considerations for Rural Development Projects. Chicago.

Henderson, H. F. and Welcomme, R.L. 1974. "The relationship of yield to morphoedaphic index and numbers of fishermen in African inland fisheries," FAO/CIFA Occasional Paper No. 1, CIFA/OP1, 19 p.

Holden, M.J. and Raitt, D.F.S., editors. 1974. "Manual of fisheries science, Part 2: Methods of resource investigation and their applications. FAO Fisheries Technical Paper No. 115, Revision 1, FIRS/T115, 214 p.

Holling, C.S., editor. 1982. Adaptive Environmental Assessment and Management. John Wiley & Sons, Chichester, UK.

Holt, S.J., compiler. 1960. Multilingual Vocabulary and Notation for Fishery Dynamics. FAO, Rome, 42 p.

Hoopes, C.C. 1970. Freshwater Fish Electro-motivator (FFEM). Industrial Sciences Group, University of Michigan, Ann Arbor, 2v.

Howard Humphreys, Ltd. 1984. "The autonomous operation of the Kekreti Reservoir," mimeo.

Huisman, E.A. and Hogendoorn, H., editors. 1979. "EIFAC workshop on mass rearing of fry and fingerlings of freshwater fishes," FAO/EIFAC Technical Paper no. 35, Suppl. 1, EIFAC/T35, 202 p.

Huismans, J.W. 1978. "The international register of potentially toxic chemicals (IRPTC): its present state of development and future plans," AMBIO.

Imeolove, D.M.A. and Adegoke, O.S., editors. The Ecology of Lake Kainjo, University of Ife Press, Ile-Ife, Nigeria.

Interim Committee for Coordination of Investigations of the Lower Mekong Basin. 1982. Nam Pong Environmental Management Research Project: Final Report for Phase III, Part I: An Integrated Simulation Model for Resource Management, 311 p.

Interim Committee for Coordination of Investigation of the Lower Mekong Basin and Lagler, K.F. 1982. Environmental Impact Assessment Guidelines for Application to Tropical River Basin Development.

International Association for Impact Assessment. 1982. Impact Assessment Bulletin, 1(3), Spring 1982.

International Association for Impact Assessment. 1982. Impact Assessment Bulletin, 2,(1) Fall 1982.

International Congress on Large Dams. 1973. Transactions. (11th, Madrid), Paris, 5 v.

International Institute for Appplied Systems Analysis. 1979. "Expect the unexpected: An adaptive approach to environmental management," Executive Report 1, IIASA, Laxenburg, Austria, 16 p.

International Workshop on Environmental Planning for Large-Scale Development Projects. 1983. "Environmental Planning for Large-Scale Development Projects, Recommendations and Actions for Implementation," Whistler, British Columbia, 2-5 October 1983.

Ita, E.O. and Petr, T. 1983. "Selected bibliography on major African reservoirs," FAO/CIFA Occasional Paper No. 10, CIFA/CPCA/OP10, 53 p.

Jackson, P.B.N. and Rogers, K.H. 1976. "Cabora Bassa fish populations before and during the first filling phase," Zoologica Africana, 11(2), p. 373-397.

Jackson, R.P.N. 1977. "The African great lakes: food source and world treasure," Biological Conservation, Applied Publishers Ltd, England, p. 303-304

Jain, R.K.; Urban, L.V.; G.S. Stacey, G.S. 1977. Environmental Impact Analysis:. A New Dimension in Decision Making, Van Nostrand Reinhold Environmental Engineering Series, Van Nostrand Reinhold Company. New York, NY.

Jamieson, D.C. and Axon, A., editors. 1984. Africa Guide 1984, World of Information, London.

Jenkins, R.M. 1965. "Bibliography on reservoir fishery biology in North America," U.S. Bureau of Sport Fisheries and Wildlife Research Report No. 68, 57 p.

Jenkins, R.M. 1970. "The influence of engineering design and operation and other environmental factors on reservoir fishery resources," Water Resources Bulletin, 6(1), p. 110-119.

Jenkins, R.M. 1976. "Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables," Annals of the Oklahoma Academy of Sciences, 5, p. 11-20.

Johannesson, K.A. and Mitson, R.B. 1983. "Fisheries acoustics: a practical manual for aquatic biomass estimation," FAO Fisheries Technical Paper No. 240, FIRM/T240, 249 p.

Johnson, H.E., and Brice, R. F. 1953. "Use of impounded water for fish culture," U.S. Fish and Wildlife Service Research Report No. 35. 35 p.

Jones, J.R. and Hoyer, M.V. 1982. "Sportfish harvest predicted by summer chlorophylla concentration in midwestern lakes and reservoirs," Transactions of the American Fisheries Society, 111, p. 176-179.

Jones, J.R. et al. 1981. "Biotic index tested for ability to assess water quality of Missouri Ozark streams," Transactions of the American Fisheries Society, 110, p. 627-637.

Josupeit, H. 1981. "The economic and social effects of the fishing industry," FAO Fisheries Circular No. 314, Revision 1, FIP/C314, 36 p.

Kapetsky, J.M. 1981. "Some considerations for the management of coastal lagoon and estuarine fisheries," FAO Fisheries Technical Paper, No. 218, FIRI/T218, 47 p.

Kapetsky, J.M. 1983. "Some fishery characteristic of coastal lagoons and estuaries," ACMARR Working Party on the Management of Living Resources in the Near-shore Tropical Waters, Working Paper No. 7, 43 p.

Kapetsky, J.M. 1984. "Management of fisheries on large African reservoirs - an overview," in Proceedings of the National Symposium on Managing Reservoir Fishery Resources, June 14-16, 1983.

Kapetsky, J.M. and Petr, T., editors. 1984. "Status of African reservoir fisheries," FAO/CIFA technical Paper 10, 326 p.

Kothari, F. 1979. "Environment and Development," Regional Seminar on Alternative Patterns of Development and Life-Styles in Asia and the Pacific, 14-18 August 1979. United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Bangkok.

Lagler, K.F. 1956. Freshwater Fishery Biology, 2nd ed. Wm. C. Brown, Dubuque, 421 p.

Lagler, K.F. 1971. "Ecological effects of hydroelectric dams," in Berkowitz, D.A. and Squires, A.M., editors, Power Generation and Environmental Change, MIT Press, Cambridge, Massachusetts, p. 133-157.

Lagler, K.F. 1974. "Consequences on the environment of building dams," in Eleventh International Congress on Large Dams, Madrid, Spain, 11-15 July, 1973, 5, p. 48-63.

Lagler, K.F. 1979. "Environmental management and water resource equipment in the Nam Pong basin of northeastern Thailand," Interim Committee for Coordination of Investigation of the Lower Mekong Basin, MKG/81, 86 p.

Lagler, K.F., editor. 1969. Man-made Lakes. UNDP/FAO, Rome, 71 p. (Also available in French as Les Lacs Artificiels).

Lagler, K.F.; Kapetsky, J.M. and Stewart, J. 1971. "The fisheries of the Kafue River flats, Zambia, in relation to the Kafue Gorge Dam," University of Michigan and Central Fisheries Research Institute, Chilanga, Zambia Technical Report 1, FI:SF/ZAM 11, 161 p.

Lannan, J. E.; Smitherman, R.O. and Tchobanoglous, G., editors. 1983. "Principles and practices of pond aquaculture: a state of the art review," Marine Science Center, Oregon State University, Newport, OR, 240 p.

Lelek A. 1982. "Ecological impact due to impoundment of Batang Balui in the Bakun area, Sarawak East Malaysia," German Agency for Technical Cooperation, 65 p.

Lelek, A. 1980. "Fische als Indikatoren der Umweltverhältnisse," Cour. Forsch, Inst. Senckenber, 41, p. 111-129.

Lelek, A. and El-Zarka, S. 1971. "Preliminary observations on the effect of Kainji Dam on the downstream fisheries," Journal of the West African Science Association, 16(2), p. 171-178.

Lelek, A. and Tobias, W. 1982. "Rapport final sur les proprietiés limnologiques, la piscifaune et le pêche industrielle dans le lac du barrage de Selingue, Republique du Mali. Annex: propositions relatives à l'activité du laboratoire de hydrobiologie de Mopti," Frankfort, 86 p.

Lelek, A.; Lelek, S. and El-Zarka, S. 1973. "Ecological comparison of the preimpoundment and postimpoundment fish faunas of the River Niger and Kainji Lake, Nigeria," Geophysical Monograph Series, 17, American Geophysical Union, Washington, D.C, p. 655-660.

Lenon, R. E. 1959. "The electrical resistivity meter in fishery investigations," U.S. Fish and Wildlife Service Special Scientific Report--Fisheries, No. 287, 13 p.

Leopold, L.B. et al. 1971. "A procedure for evaluating environmental impact, Geological Survey Circular 645, U.S. Government Printing Office, Washington, D.C., 13 p.

Leopold, M. 1981. "Problems of fish culture economics with special reference to carp culture in Eastern Europe," FAO/EIFAC Technical Paper No. 40, EIFAC/T40, 99 p.

Lesack, L.F.W. 1974. "Seasonal catch-effort dynamics, composition and distribution of fishes in the riverine artisanal fishery in The Gambia, West Africa," 38 p. (Ms.).

Liang, Y. and van der Schalie, H. 1975. (Abstract) "Cultivating Fossaria bulimoides (Lea), a snail host of the liver fluke, fasciola hepatica," Malacological Review, 8, p. 123.

Little, E.C.S. 1979. "Handbook of utilization of aquatic plants: A review of world literature," FAO Fisheries Technical Paper No. 187, FIRI/T187, 176 p.

Loiselle, P.V. 1972. "Ghana preliminary survey of inshore habitats in the Volta Lake," FAO Volta Lake Research Project, FI:DP/GHA/67/510/2, 122 p.

Maar, A.; Mortimer, M.A.E. and Van Der Lingen, I. 1966. Fish Culture in Central East Africa. FAO, Rome, 158 p.

Marshall, B.E. 1983. "Towards predicting reservoir ecology and fish yields from preimpoundment physicochemical data," 45 p. (Ms.).

Mathes, J.C. and Stevenson, D.W. 1976. Designing Technical Reports. Bobbs-Merrill, Indianapolis, IN, 72 p.

Matthes, H. 1973. A Bibliography of African Freshwater Fish. FAO, Rome, 299 p.

Matuszek, J. E. 1978. "Empirical predictions of fish yields of large North American lakes," Transactions of the American Fisheries Society, 197 (3), p. 385-394.

McAllister, Donald M. 1980. Evaluation in Environmental Planning: Assessing Enviromental, Social, Economic and Political Trade-offs. The MIT Press, Cambridge, MA, 1980.

Medina-Gandara, J.A. and Sanchez Silva, R. 1977. "Impacto ambiental de las obras hidraulicas," Documentacion de la Comision del Plan Nacional Hildraulico, Mexico City, Mexico, 70 p.

Mekong Committee. 1970. "Report of the seminar on the draft amplified basin plan report," United Nations, E/CN.11/WRD/MKG/L.3118, 55 p.

Mekong Committee. 1970. "Report on indicative basin plan, a proposed framework for the development of water and related resources of the lower Mekong Basin," United Nations, E/CN.11/WRD/MKG/L.340, 6 chapters, 11 annexes, paged separately.

Mekong Committee. 1974. "Final report of the ad hoc panel of environmental consultants," UN Economic and Social Council, E/CN.11/WRD/MKG/L.402, 139 p.

Mekong Committee. 1976. "Fisheries and integrated Mekong River basin development," terminal report of the Mekong basinwide fishery study, Karl F. Lagler, director, School of Natural Resources, University of Michigan, Ann Arbor, MI, 3v.

Moller, F. 1979. "Manual of methods in aquatic environment research, part 5: statistical tests," FAO Fisheries Technical Paper No. 182. FIRI/T182, 131 p.

Mottet, M.G. 1980. "Factors leading to the success of Japanese aquaculture," Technical Report No. 52. Washington Department of Fisheries, Olympia WA, 83 p.

Moxon, J. 1969. Volta: Man's Greatest Lake. Andre Deutsch, London, 256 p.

Munn, R.E., editor. 1981. Environmental Impact Assessment, Principles and Procedures, 2nd ed. John Wiley & Sons, Chichester, UK.

N'Jie, A.E. 1982. An Introductory Manual of Identification of Common Marine Species (External Features). Publication No. 34, Gambia Fisheries Department, Banjul, The Gambia, 44 p.

Nédélec, C. 1982. "Definition and classification of fishing gear categories," FAO Fisheries Technical Paper, No. 222, FIDI/ FIIT/T222, 51 p.

Needham, J.G., and Needham, P. R. 1951. A Guide to the Study of Freshwater Biology, 4th ed. Comstock Publishing Co., Ithaca, N.Y., 88 p.

Neiland, H. 1980. "Qualitative and quantitative aspects of the food Ethmalosa fimbriata (Bowdich) in the Ebrie Lagoon (Ivory Coast)," Doc. Scient. Centre Rech. Oceanogr. Abidjan, 77(7) June 1980, p. 85-95.

Nelson, M.L.; Gangstad, E. O. and Seaman, D. E. 1970. "Report on potential growth of aquatic plants of the lower Mekong River basin -- Laos, Thailand," US Corps of Engineers, Washington, D.C., 98 p.

New, M.B., and Singholka, S. 1982. "Freshwater prawn farming: A manual for the culture of the Macrobrachium rosenberrgii," FAO Fisheries Technical Paper No. 225, FIRI/T225 (En), 116 p.

Newman, G. 1977. "The living marine resources of the Southeast Atlantic," FAO Fisheries Technical Paper No. 178, FIR/T178(EN), 59 p.

Norling, I. 1968. "Economic evaluation of inland sport fishing," FAO/EIFAC, Technical Paper No. 7. EIFAC/T7, 96 p.

OMVG. 1985. "Summary report of the meeting of Universty of Michigan representatives and Member States OMVG, Banjul, July 8-11, 1985," mimeo.

OMVS, n.d. "Assessment of Environmental Effects of Proposed Developments in the Senegal River Basin," Plan of Action and Final Report. Gannet, Fleming, Corddry, and Carpenter, Inc.

Odum, E.P. 1963. Ecology. Holt, Rinehart Winston, New York, 152 p.

Oglesby R.T.; Carlson, C.A. and McCann, J.A., editors. 1972. River Ecology and Man. Academic Press, New York, 465 p.

Ortolando, Leonard. 1982. "Environment assessment in water resources planning," Water Supply and Management, 2, p. 159-176.

Panayotou, T. 1982. "Management concepts for small-scale fisheries," FAO Fisheries Technical Paper No. 228, FIPP/ T228, 53 p.

Panel of Experts on Environmental Management for Vector Control (PEEM). 1983. "Report of the Third Meeting." PEEM Secretariat, World Health Organization, Geneva, VBC/83.4. 71 p.

Paperna, I. 1980. "Parasite, infections and diseases of fish in Africa," FAO/CIFA Technical Paper No. 7, CIFA/T7, 216 p.

Pauly, D. 1980. "A selection of simple methods for the assessment of tropical fish stocks," FAO Fisheries Circular No 729, FIRM/C729, 54 p.

Pearson, S.; Stryker, D. et. al. 1981. Rice in West Africa. Stanford University Press, Palo Alto.

Pfritzer, D.W. 1959. "Reservoir and tailwater bibliography with special reference to the southeastern United States," revised, U.S. Bureau of Sport Fisheries and Wildlife, Branch of River Basin Studies, Atlanta, 40 p.

Pikus, I., editor. 1985. "National Science Foundation Panel Review of Gambia River Basin Studies."

Pollnac, R.B., editor. 1977. "Panamanian small-scale fishermen," Marine Technical Report No. 44, International Center for Marine Resource Development, University of Rhode Island, Kingston, R.I., 88 p.

Polytechna. 1981. Plan Geeral D'Aménagement Hydraulique de la Moyenne Guineé.

Pope, J.A. et al. 1975. "Manual of methods for fish stock assessment, part 3: selectivity of fishing gear," FAO Fisheries Technical Paper No. 41, Revision 1, FIRS/T41, 65 p.

Portmann, J.E., editor. 1976. "Manual of methods in aquatic environment research, Part 2: Guidelines for the use of biological accumulators in marine pollution monitoring," FAO Fisheries Technical Paper No. 150, FIFI/T150, 76 p.

Powers, J. E. and Lackey, R.T. 1976. "A multiattribute utility function for management of a recreational resource," Virginia Journal of Science, 27, p. 191-198.

Prieur, M. and Lambrechts, C. 1980. "Model outline environmental impact statement from the standpoint of integrated management or planning of the national environment," Nature and Environment Series, No. 17, Council of Europe, Strasbourg.

Printz, A.C., Jr. 1983. "Environmental assessment: a tool for systemwide cooperation," Horizons, February, 1983, p. 22-25.

Rau, J.G. and Wooten, D.C., editors. 1984. Environmental Impact Analysis Handbook. McGraw-Hill, New York.

Reid, G.K. and Wood, R.D. 1976. Ecology of Inland Waters and Estuaries, 2nd ed. Van Nostrand, New York, 485 p.

République du Sénégal. 1984. "Deuxieme Lettre de Mission entre le Gouvernment du Sénégal et La Societé d'Aménagement et d'Exploitation des Terres du Delta du Fleuve Sénégal et des Vallées du Fleuve Sénégal et de la Falémé (1984/85-1985/86-1986/87)." Ministre du Dévélopement Rural, Saint Louis, Decembre 1984.

Responsibility, Data and Institutional Development, no. 625-0620A, USAID/Senegal, Project Paper Amendment."

Rhein-Ruhr Ingenieur-Gesellschaft. 1983. Anti-Salt Bridge-Barrage.

Rickers, W.E. 1975. "Computation and interpretation of biological statistics of fish populations," Bulletin of the Fisheries Research Board of Canada, 191, 382 p.

Riley, J.P.; Andersen, J.C. et al. 1981. "Cost allocation alternatives for the Senegal River development program." Utah Water Research Laboratory, Utah State University, Logan, Utah.

Roberts, T.R. and Stewart, D.J. 1976. "An ecological and systematic survey of fishes in the rapids of the Lower Zaire or Congo river," Bulletin of the Museum of Comparative Zoology, 14(9), p. 240-316.

Rubin, N. and Warren, W.M., editors. 1968. Dams in Africa: An Inter-disciplinary Study of Man-made Lakes in Africa. Frank Cass, London.

Ryder, R.A. et al. 1974. "The morphoedaphic index, a fish yield estimator -- review and evaluation," Journal of the Fisheries Research Board of Canada, 31 (5), p. 663-688.

SONED Afrique-Courtoy. 1980. "Projet de développement rural au Sénégal-Oriental et en Haute Casamance," Vol. 1-4, Ministere du Développement Rural, République au Sénégal.

Saile, S. B. and Roedel, P. M., editors. 1980. "Stock assessment for tropical small-scale fisheries," International Center for Marine Resource Development, University of Rhode Island, Kingston, RI, 198 p.

Sasekumar, A. and Loi, J.J. 1983. "Litter production in three mangrove forest zones in the Malay peninsula," Aquatic Botany, 17 (1983), p. 283-290.

Saville, A., editor. "Survey methods of appraising fishery resources," FAO Technical Paper No. 171, FIRS/T171, 76 p.

Schneider, C.R. 1974. "Snail transmission of schistosomiasis in the Lower Mekong Basin, with observations on other waterborne diseases," Smithsonian Institution Office of International and Environmental Progams, Washington, D.C., 229 p.

Schneider, J.C. 1975. "Typology and fisheries potential of Michigan lakes," Michigan Academician, 8(1), p. 59-84.

Schneider, J.C. 1978. "Predicting the standing crop of fish in Michigan lakes," Fisheries Research Report No. 1860, Michigan Fisheries Division, 10 p.

Schwartz, F.J. and Howland, P.A. 1978. "Evaluating gear and factors affecting catch and sampling variation," University of North Carolina Institute of Marine Sciences, Morehead City N.C., 99 p.

Scientific Committee on Oceanographical Research Working Group 33. 1974. "A review of methods used for quantitative phytoplankton studies," UNESCO Technical Papers in Marine Science, No. 18, UNESCO, Paris, 27 p.

Scientific Committee on Problems of the Environment Working Group on Man-Made Lakes (SCOPE). 1972. "Man-made lakes as modified ecosystems," Scope Report 2, ICSU, Paris, 76 p.

Scientific Committee on Water Research, International Council of Scientific Unions. 1971. "Symposium on man-made lakes, their problems and environmental effects" (abstracts of papers), COWAR, Urbana, IL, 234 p.

Scudder, T. "River Basin Development and Local Initiative in African Savanna Environments," in Human Ecology in Savanna Environments, Harris, D.R., editor, Academic Press, London.

Scudder, T. 1972. "Ecological bottlenecks and the development of the Kauba Lake Basin," in The Careless Technology, Farvar, M.T. and Milton, J.P., editors, Natural History Press, Garden City, NY, p. 206-238.

Scudder, T. 1981. "African River Basins," California Institute of Technology and Institute for Development Anthropology, Pasadena, CA, mimeo.

Scudder, T. 1985. "The Gambia River Basin Development Study Meeting of the NSF Evaluation Panel: Commentary," mimeo.

Scudder, T. and E.F. Colson. 1972. "The Kariba Dam project," in Technology and Social Change, H.R. Bernard and P. Pelto, editors, MacMillan, New York, 39-69 p.

Shaner, W.W.; Philipp, P.F.; and Schmehl, W.R. 1982. Farming Systems Research and Development, Guideleines for Developing Countries. Westview Press, Boulder, Colorado.

Shedhaden, Z.H., editor. 1975. "Report of the Symposium on aquaculture in Africa," FAO/CIFA Technical Paper No. 4, CIFA/T4, 36 p.

Shireman, J.V. and Smith, C.R. 1983. "Synopsis of biological data on the grass carp, Ctenopharyngodon idella," FAO Fisheries Synopsis No. 135, FIR/S135, 85 p.

Shopley, J.B. and Fuggle, R. F. 1984. "A comprehensive review of current environmental impact assessment methods and techniques," Journal of Environmental Management.

Simpson, A.C. 1977. "The role of research in fisheries development," FAO Fisheries Circular No. 720, FIDP/C720, 17 p.

Smith, I.R. 1979. A Research Framework for Traditional Fisheries. ICLARM, Manila, 40 p.

Smith, P. E. and Richardson, S. L. 1977. "Standard techniques for pelagic fish egg and larva surveys," FAO Fisheries Technical Paper No. 175, FIR/T175, 100 p.

Smith, P. E. and Richardson, S. L. 1979. "Selected bibliography on pelagic fish egg and larva surveys," FAO Fisheries Circular No. 706, FIR/C706, 97 p.

Smith, R.F.; Swartz, A.H. and Massman, W.H., editors. 1966. "A symposium on estuarine fisheries," American Fisheries Society Special Publication No. 3, 154 p.

Snedaker, S.C. 1978. "Mangroves: their value and perpetuation," Nature and Resources, 14(2), p. 6-13.

Song, Z., compiler. 1980. "Manual of small-scale reservoir fish culture," FAO Fisheries Circular No. 727, FIRI/C727, 18 p.

Sonntag, N.C.: Everitt, R.R. and Staley, M.J. 1980. Simulation Modelling: The Tool of Adaptive Environmental Assessment and Management, ESSA Environmental and Social Systems Analysis, Vancouver, British Columbia.

Spailing, E.W. 1981. "A survey and analysis of ex-post cost benefit studies of Sahelian irrigation projects," Colorado State University, Department of Economics, Fort Collins, CO.

Stanley, N.F. and Alpers, M.P., editors. 1975. Man-made Lakes and Human Health, Academic Press, London.

Sterling, C. 1971. "Aswan Dam: predictions came true with a vengeance," Washington Post, Feb. 15, p. 15.

Sterling, C. 1971. "Environmental problems face a new super-dam," Washington Post, Jan. 11 1977, p. 17.

Stirn, J. 1981. "Manual of methods in aquatic environment research, part 8: ecological assessment of pollution effects," FAO Fisheries Technical Paper No. 209, 70 p.

Streeten and Associates. 1981. First Things First. Oxford University Press, London.

Sundararaj, B.I. 1981. "Reproductive physiology of teleost fishes," FAO/UNDP Aquaculture Development and Coordination Programme, ADCP/REP/81/16, 82 p.

Swanson, G. A., technical coordinator. 1979. "The Mitigation Symposium: a national workshop on mitigating losses of fish and wildlife habitats," General Technical Report RM-65, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, 684 p.

Teas, H. J., editor. 1984. Physiology and Management of Mangroves. Dr. W. Junk Publishers, The Hague.

Teinsongrusmee, B. 1967. "A Bibliography of systematic and biology of shrimps (Penaeidae)," Contribution No. 6, Marine Fisheries Laboratory, Department of Fisheries, Ministry of Agriculture. Bangkok, 103 p.

Tomczak, G.H. 1977. "Environmental analyses in marine fisheries research-fisheries environmental services," FAO Fisheries Technical Paper No. 170, FIRI/T170, 141 p.

Tressler, D.K. and Lemon, J. McW. 1951. Marine Products of Commerce. 2nd ed. Reinhold Publishing, New York, 782 p.

U.S. Agency for International Development. 1981. "OMVS - Fiscal Allocation."

U.S. Agency for International Development. "Prospects for Small-Scale Development in the Sahel," The Sahel USAID Water Management Synthesis II Project, WMS Report 26.

U.S. Army Corp of Engineers. 1963. "Seminar on river basin planning, Ft. Belvoir, Virginia 27-31 May 1963," Department of Army, Office of the Chief of Engineers, Washington, D.C., 483 p.

UNDP. 1976. Guidelines on Project Formulation, G3400-2, 118 p.

UNDP. 1977. Multidisciplinary Mission Multidonor Mission, March-April 1977. Development of the Gambia River Basin, 2 vols, Programme of Action, Résumé Preliminaire, United Nations Development Programme. New York.

UNESCO. 1981. Bibliography on Mangrove Research, UNESCO, Paris, 479 p.

USAID. 1984. "Mid-term project evaluation Gambia River Basin Development Project," USAID/Senegal, River Basin Development Office, mimeo.

Ulltang, O. 1977. "Methods of measuring stock abundance other than by the use of commercial catch and effort data," FAO Fisheries Technical Paper No. 176, FIRS/T176, 23 p.

United Nations Economic and Social Council. 1974. "Final Report: Ad Hoc Panel of Environmental Consultants, Committee for Co-ordination of Investigations of the Lower Mekong Basin," 10 December 1974.

United Nations. 1979. Water Management and Environment in Latin America. United Nations Economic Commission for Latin America, Pergamon Press, NY.

United Nations. 1983. "Experiences in the Development and Management of International River and Lake Basins," Proceedings of the United Nations Interregional Meeting of International River Organizations, Dakar, Senegal, 5-14 May 1981, United Nations, New York.

United States Bureau of Sport Fisheries and Wildlife. 1961. "Reservoirs: a prospectus for sport fishery research," Bureau of Sport Fisheries and Wildlife, Washington, D.C, 30 p.

United States Committee on Large Dams, the Committee on Failures and Accidents to Large Dams. 1975. "Lessons from dam incidents, USA," American Society of Civil Engineers, New York, 387 p.

Vibert, R. and Lagler, K.F. 1961. Pêches continentales biologie et amenagement. Dunod, Paris, 719 p.

Vincke, P. 1982. "Catfishes of the genus Clarias: A general bibliography," FAO Fisheries Circular No. 739, FIRI/ C739, 39 p.

Ward, G.S. and Parrish, P.R. 1982. "Manual of methods in aquatic environment research, Part 6: toxicity tests," FAO Fisheries Technical Paper No. 185, FIRI/T185, 23 p.

Wei, J. 1980. "Aswan and after: the taming and transformation of the River Nile," The Research News, The University of Michigan, Ann Arbor, 31(7), p. 1-29.

Welcomme, R. L. 1983. "River Basins," FAO Technical Paper No. 202, Fishery Resources and Environmental Division, Food and Agriculture Organization, Rome.

Welcomme, R.L. "Some General and Theoretical Consideration on the Fish Production of African Rivers," CIFA Occasional Paper No. 3, Food and Agriculture Organization, Rome.

Welcomme, R.L. 1975. "L'écologie des pêches dan les plaines inondable Africaines," Document Technique du CPCA No. 3, CPCA/T3, 51 p.

Welcomme, R.L. 1975. "The fisheries ecology of African floodplains," FAO/CIFA Technical Paper No. 3, CIFA/T3, 51 p.

Welcomme, R.L. 1978. 'Symposium on river and floodplain fisheries in Africa," FAO/CIFA Technical Paper No. 5, CIFA/T5, 378 p.

Welcomme, R.L. 1979. "Fishery management in large rivers," FAO Fisheries Technical Paper No. 194, FIRI/T194, 60 p.

Welcomme, R.L. 1979. "Fishery management in large rivers," FAO Fisheries Technical Paper No. 194, FIRI/T194, 60 p.

Welcomme, R.L. 1979. "Les pêches continentales d'Afrique," FAO/CPCA Document No. 7, CPCA/OP7, 77 p.

Welcomme, R.L. 1983. "River basins," FAO Fisheries Technical Paper No. 202, FIR/T202, 60 p.

Welcomme, R.L. and Hagborg, D. 1977. "Towards a model of a floodplain fish population and its fishery," Env. Biol. Fish., 2(1), p. 7-244.

Welcomme, R.L. and Henderson, H.F. 1976. "Aspects of the management of inland waters for fisheries," FAO Fisheries Technical Paper No. 161, FIRS/T161, 36 p.

Welcomme, R.L., editor 1975. "Symposium on the methodology for the survey, monitoring and appraisal of fishery resources in lakes and large rivers," FAO/EIFAC Technical Paper No. 23 (Supplement 1) Vol. I, pp 1-435, Vol II, pp. 436-747.

White, G.F. 1977. Environmental Effects of Complex River Development. Westview Special Studies in Natural Resource and Energy Management, Boulder, CO.

Widstrand, C. 1978. Environmental and Social Effects of Water Management in Development. Pergamon Press, NY.

Williams, R.B. 1966. "Annual phytoplanktonic production in a system of shallow temperature estuaries," in Some Contemporary Studies in Marine Science, Harold Barnes, editor, George Allen and Unwin, London, p. 699-716.

Winberg, G.G., editor. 1971. "Symbols, units and conversion factors in studies of freshwater productivity," International Biological Programme, London, 23 p.

World Bank. 1981. The Gambia - Basic Needs in The Gambia, A World Bank Country Study. The International Bank for Reconstruction and Development/The World Bank, Washington, D.C.

World Bank. 1984. "Environmental Policies and Procedures of the World Bank," The World Bank, Washington, May 1, 1984.

World Bank. 1984. Impact Evaluation Report - The Gambia Agricultural Development Project. The World Bank, 1984.

Worthington, E.B., editor. 1977. Arid Land Irrigation in Developing Countries: Environmental Problems and Effects. Pergamon Press, NY.

Woynarovich, E. 1980. Cartilla del piscicultor. Republic of Venuzuela, National Office of Fisheries, 111 p.

Woynarovich, E. and Horvath, L. 1981. "La reproduction artificielle des poissons en eau chaude: manual de Vulgarisation," FAO Document technique sur les pêches No. 201, FIR/T201, 191 p.

Y. Bajard Associates Ltd. 1976. "Development of the Gambia River Basin: proposal for a plan of action appendix groundwater-drainage," The Company, Vancouver, 96 p.

Zuboy, J.R. and Lackey, R.T. 1975. "A computer simulation model of a multispecies centrarchid population compex," Virginia Journal of Science, 26(1), p. 13-19.

van der Schalie, H. 1972. "World Health Organizations Project Egypt 10: A case history of a schistosomiasis control project," in The Careless Technology, Farvar, M.T. and Milton, J.P., editors, Natural History Press, New York, p. 116-136.

van der Schalie, H. 1974. "Aswan Dam revisited," Environment, 16(9), p. 18-26.

van der Schalie, H. 1973. "Dam(n) large rivers -- then what"? The Biologist, 55(1), p. 29-33.

von Brandt, A. 1979. "Bibliographie pour la formation des pecheurs," FAO document technique sur les pêches No. 195, FIIT/T19, 71 p.

ANNEX A.

UM GRBS WORKING DOCUMENTS

UNIVERSITY OF MICHIGAN GAMBIA RIVER BASIN STUDIES

WORKING DOCUMENTS

1. Materials towards a bibliography related to Gambia Basin development. Banjul: UM GRBS, 3 March 1983. 70 p.

2. Work plan for socioeconomic studies in relation to proposed dams in the People's Revolutionary Republic of Guinea, by William Derman. Banjul: UM GRBS, 3 March 1983. 12 p.

3. Criteria for selection of villages for intensive socioeconomic study in the Gambia River Basin of The Gambia and Senegal, by Peter M. Weil. Banjul: UM GRBS, 23 February 1983. 37 p.

4. Gambia River Basin Studies Work Plan. Ann Arbor: UM GRBS, March 1983. 171 p. Plus three addenda of later date.

5. Material towards an illustrated key to the fishes of the Gambia River and estuary, by Walter J. Rainboth. Ann Arbor: UM GRBS, May 1983. 613 p.

6. A review of data processing requirements for socioeconomics, by Gerald A. Cole. Ann Arbor: UM GRBS, 1 June 1983. 28 p.

7. Guideline for fishery economic investigations, by Henri P. Josserand. Banjul: UM GRBS, 20 June 1983. 11 p.

8. Hydrology in relation to development in the Gambia River Basin, by Michael Jasinski. Banjul: UM GRBS, 31 July 1983, 29 p.

9. Material on medical establishment in OMVG Member States, by Sara McAndrew. Banjul: UM GRBS, 30 July 1983. 67 p.

10. Socioeconomic reconnaissance Kedougou-Kekreti area, Senegal Oriental, by William Derman. Banjul: UM GRBS, 8 February 1983. 27 p.

11. Proposed plan of study for a survey on the development and organization of irrigation perimeters in the Gambia River Basin, by Christine Scharffenberger. Banjul: UM GRBS, July 1983. 6 p.

12. Program of reconnaissance for "Socioeconomic impact case study of the Balingho barrage" and related "Agricultural extension and input provision case study", by Cynthia Moore. Banjul: UM GRBS, August 1983. 7 p.

13. Work plan for socioeconomic studies in the Kekreti Dam area, Senegal, by Walter West. Banjul: UM GRBS, July 1983. 20 p.

14. Reconnaissance for socioeconomic downstream impact assessment of the Balingho barrage, by Cynthia Moore and Moussa Ceesay. Banjul: UM GRBS, August 1983. 38 p.

15. The design and relevance of intensive village surveys to river basin development projects, by John Sutter. Banjul: UM GRBS, September 1983. 25 p.

16. Expanded materials on the study of hydrology in relation to development in the Gambia River Basin, by Michael Jasinski. Banjul: UM GRBS, September 1983. 25 p.

17. Notes on involvement of the governments of the OMVG member states in the Gambia River Basin Studies of The University of Michigan (GRBS) for USAID and OMVG, by Karl F. Lagler. Banjul: UM GRBS, October 1983. 18 p.

18. Revised basinwide work schedules, by team and project quarter, by Karl F. Lagler. Banjul: UM GRBS, 15 November 1983. 31 p.

19. Scope of animal health impact studies, by Marinus van den Ende. Banjul: UM GRBS, 26 September 1983. 7 p.

20. Floodplain ecology -- Gambia River, The Gambia, by Alfred M. Beeton. Banjul: UM GRBS, 18 January 1984. 22 p.

21. Farming system survey in the Senegambia portion of the Gambia River Basin between Georgetown vicinity, The Gambia, and Kedougou vicinity, Senegal Oriental (Socioeconomic study zone 3), by Richard Swanson. Banjul: UM GRBS, 24 January 1984. 27 p.

22. Farming system survey in the Senegambia portion of the Gambia River Basin, by Franklin Casey, Cynthia Moore and Richard Swanson. Banjul: UM GRBS, 24 January 1984. 27 p.

23. Gambia River "Balingho" bridge-barrage impact study -- Rice cultivation systems, by Judith Carney. Banjul: UM GRBS, 24 January 1984. 10 p.

24. Artisanal fisheries of the Gambia River: review and directives for Univeristy of Michigan studies, by John A. Dorr, Philip J. Schneeberger and Ousman K. L. Drammeh (Fisheries Department, Ministry of Water Resources and Environment, Banjul). Banjul: UM GRBS, December 1983. 27 p.

25. Aquatic ecology and resources of the Gambia River, Senegambia -- sampling strategy and selected findings, June through September 1983, by Russell A. Moll and John A. Dorr. Banjul: UM GRBS, January 1984. 84 p.

26. Observations on the terrestrial flora, fauna and ecology of the Guinean headwaters region of the Gambia River Basin, by Peter L. Ames, B. Dean Treadwell, Dario Rodriguez-Bejarano and Janis A. Carter. Banjul: UM GRBS, 24 February 1984. 73 p.

27. Snail intermediate hosts of human schistosomiasis in The Gambia and Senegal, by Emile A. Malek. Banjul: UM GRBS, 16 February 1984. 17 p.

28. Economic data on fisheries of the Gambia River and adjacent coastal waters, by Henri P. Josserand, Musa A. Saidykhan and Amadou A. Gueye. Banjul: UM GRBS, 16 March 1984. 16 p.

29. Gambia River Basin Studies data processing and data management ,by Leonard Malczynski. Banjul: UM GRBS, 16 March 1984. 16 p.

30. Socioeconomic impacts of proposed Kekreti dam, Gambia River, Senegal Oriental, by Walter West. Banjul: UM GRBS, 1 April 1984. 75 p.

31. Costs of mitigating measures for public health in the Gambia River Basin, by Marty Makinen. Banjul: UM GRBS, 30 March 1984. 24 p.

32. A dictionary of scientific and local names for fish commonly occurring in The Gambia's territorial waters, by Musa A. Saidykhan. Banjul: UM GRBS, 11 April 1984. 16 p.

33. Animal health in the upper Gambia River Basin: potential effects of river development, by Marinus van den Ende. Banjul: UM GRBS, 16 April 1984. 62 p.

34. A food and nutrition surveillance system for the Gambia River Basin, by Tonia Marek. Banjul: UM GRBS. 102 p.

35. Rural water supply and sanitation in the Gambia River Basin, by D. M. B. Jagne (Consultant in Public Health). June 1984. 29 p.

36. Environmental effects of proposed mining-related activities in the Gambia River Basin, by Robert E. Moran. Banjul: UM GRBS, 4 June 1984. 46 p.

37. Aquatic ecology and resources of the Gambia River: selected findings, October 1983 through January 1984, by Russell A. Moll, Thomas D. Berry, Marcus J. Healey, Loren E. Flath, Gerald L. Krausse, Donna Page, Philip J. Schneeberger, Heang T. Tin, and Marion van Maren. Banjul: UM GRBS, May 1984. 352 p.

38. Description and evaluation of the river resources team training program, by John A. Dorr and Russell A. Moll. Banjul: UM GRBS, 1 June 1984. 21 p.

39. Economic importance of the Gambia fisheries and implications of river basin development, by Henri P. Josserand. Banjul: UM GRBS, June 1984. 70 p.

40. An assessment of performance and productivity of irrigated agriculture in The Gambia and Senegal, by Robert B. Kagbo. Banjul: UM GRBS, June 1984. 18 p.

41. Acid-sulphate soils: the constraints they impose on the Gambia's antisalinity barrage scheme, by Raymond Colley. Banjul: UM GRBS, July 1984. 39 p.

42. The People's Republic of China irrigated rice project in The Gambia, by Deborah Brautigam. Banjul: UM GRBS, 25 June 1984. 36 p.

43. Draft materials on analytical methodology for economics and tradeoffs in public health, by Marty Makinen. Banjul: UM GRBS, September 1984. 16 p.

44. Some facts and figures of the Gambia River Basin, by Dario Rodriguez-Bejarano. Banjul: UM GRBS. 9 p.

45. The West African Manatee Trickechus Senegalensis Link 1795, by W. Herbert L. Allsopp, Small World Fishery Consultants, Inc. Banjul: UM GRBS, September 1984. 5 p.

46. Socioeconomic and environmental considerations relative to an antisalinity barrage on the Gambia River at the Balingho, The Gambia, by Judith A. Carney. Banjul: UM GRBS, September 1984. 87 p.

47. Migration patterns in the Gambia River Basin: the impact of river basin development, by Lucie G. Colvin. Banjul: UM GRBS, November 1984. 27 p.

48. Studies on adult, juvenile and larval fishes of the Gambia River, West Africa, 1983-1984, by John A. Dorr, Philip J. Schneeberger, Heang T. Tin, and Loren E. Flath. Banjul: UM GRBS, December 1984. Approx 300 p.

49. Macroinvertebrate bottom fauna of the Gambia River, West Africa, by Marion J. van Maren. Banjul: UM GRBS, December 1984. Approx. 110 p.

50. Plankton assemblages of the Gambia River, West Africa, by Marcus J. Healey, Donna Page, and Russell A. Moll. Banjul: UM GRBS, December 1984. Approx. 160 p.

51. Physical and chemical environment of the Gambia River, West Africa, 1983-1984, by Thomas D. Berry, Russell A. Moll and Gerald L. Krausse. Banjul: UM GRBS, December 1984. Approx 175 p.

52. An analysis of mangrove forests along the Gambia River estuary: implications for the management of estuarine resources, by Robert R. Twilley. Banjul: UM GRBS, December 1984. 82 p.

53. Gambia River Basin Studies -- hydrology, by Harza Engineering Company International. Banjul: UM GRBS, December 1984. 168 p.

54. Health situation in the Republic of Guinea, by Evelyne Laurin. Ann Arbor: UM GRBS, December 1984. 79 p.

55. An indigenous perspective of health and disease in Guinea, by Alice Hamer. Ann Arbor: UM GRBS, December 1984. 55 p.

56. An overview of nutritional status in the Gambia River Basin in Guinea, by Alice Hamer. Ann Arbor: UM GRBS, January 1985.

57. Designing Gambia River Basin Studies reports, by J.C. Mathes. Ann Arbor: UM GRBS, 1984.

58. Mangrove forests of the Gambia River Basin: current status and expected changes, by Samuel C. Snedaker. Ann Arbor: UM GRBS, 1984. 32 p.

59. Effects of river development projects on soil erosion in the upper Gambia River Basin, by Janneke van Krimpen. Banjul: UM GRBS, 1984.

60. Chimpanzees in the Gambia River Basin, by Janice Carter. Banjul: UM GRBS, 1985.

61. Manatees in the Gambia River Basin and potential impact of the Balingho Antisalt Dam, by James A. Powell. Ann Arbor: UM GRBS, 1984. 76 p.

62. Land use and vegetation patterns in the Gambia River Basin, by Dario Rodriguez-Bejarano. Ann Arbor: UM GRBS, 1984. 92 p.

63. Wildlife in the Gambia River Basin, by B. Dean Treadwell and Peter L. Ames. Ann Arbor: UM GRBS, 1984. 170 p.

64. A study of irrigation and irrigated perimeters in The Gambia, by Lamin O. Jobe. Ann Arbor: UM GRBS, 1985. 70 p.

65. Gambia River Basin integrated impact assessment methodology, by Karl F. Lagler and J.C. Mathes. Ann Arbor: UM GRBS, 1985.

66. Impact survey of Kouya, Kankoure and Kogou Foulbe damsites in the Republic of Guinea, by William C. Roberts. Ann Arbor: UM GRBS, 1985.

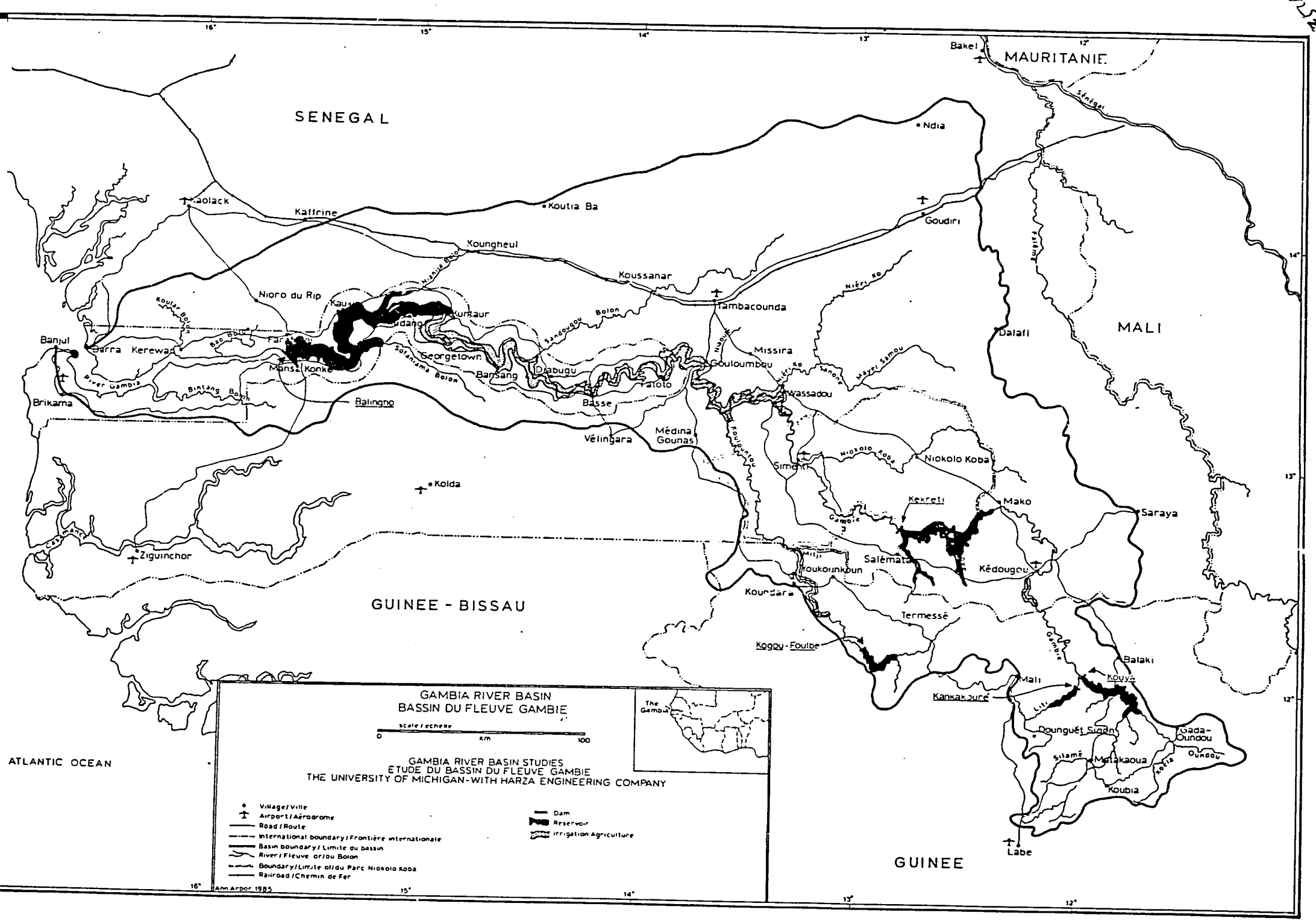
67. Socioeconomic field data collection and management: Gambia River Basin Studies, by Cynthia Moore, Frank Casey and Len Malczynski. Ann Arbor: UM GRBS, 1985.

68. Gambia River Basin Studies: irrigation case study for Senegal Oriental, by Jean LeBloas. July 1984.

69. Senegalese farming systems in the Gambia River Basin, by Frank Casey and Cynthia Moore. Ann Arbor: UM GRBS, August 1985.

70. Fishery management components, by Karl F. Lagler. Ann Arbor: UM GRBS, October 12, 1984.

71. Benefit/cost analysis of Gambia River Basin Development Studies projects, by Sarah Lynch. Ann Arbor: UM GRBS, September 1985.


GAMBIA RIVER BASIN
BASSIN DU FLEUVE GAMBIE
scale / echelle
0
Km
100
GAMBIA RIVER BASIN STUDIES
ETUDE DU BASSIN DU FLEUVE GAMBIE
THE UNIVERSITY OF MICHIGAN-WITH HARZA ENGINEERING COMPANY
Village/Ville
Airport/Aérodrome
Road/Route
International boundary/Frontière internationale
Basin boundary/Limite du bassin
River/Fleuve or/ou Bolon
Boundary/Limite of/du Parc Niokolo Koba
Railroad/Chemin de Fer
Dam
Reservoir
Irrigation Agriculture
The Gambia
Ann Arbor 1985
SENEGAL
MAURITANIE
MALI
GUINEE - BISSAU
GUINEE
ATLANTIC OCEAN
Bakel
Ndia
Kaolack
Kaffrine
Koutia Ba
Goudiri
Koungheul
Koussanar
Nioro du Rip
Tambacounda
Banjul
Barra
Kerewan
Brikama
Mansa Konko
Georgetown
Bansang
Dabugu
Fatoto
Basse
Balingho
Vélingara
Médina Gounas
Missira
Gouloumbou
Wassadou
Dalafi
Niokolo Koba
Simenti
Kekreti
Mako
Saraya
Salémata
Moukounkoun
Kédougou
Koundara
Termessé
Kogou - Foulbe
Balaki
Kouya
Mali
Kankakouré
Dounguet Sigan
Gada-Oundou
Oundou
Sitamé
Matakaoua
Koubia
Labe
Ziguinchor
Kolda
Sénégal
Gambie
Niokolo Koba
Koulountou
Niéri Ko
Mayri Samou
Sandougou
Boion
Nizanja Bolon
Koulor Bolon
Bao Bolon
Sofanima Bolon
Bintang Bolon
River Gambia
Casamance
Koila
Oundou
Lili
Silamé
16°
15°
14°
13°
12°