

THE IMPACT OF LARGE WATER PROJECTS ON THE ENVIRONMENT



UNEP
EMINWA
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IHP

The impact of large water projects on the environment

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PREFACE

Although the total amount of water on Earth is generally assumed to have remained virtually constant during recorded history, periods of flood and drought have challenged the intellect of man to have the capacity to control the water resources available to him. Currently, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" philosophy -- either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management, however, should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to the solution of the world's water problems, Unesco, in 1965, began the first worldwide programme of studies of the hydrological cycle -- the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the Decade proved to be of great interest and value to Member States. By the end of that period a majority of Unesco's Member States had formed IHD National Committees to carry out the relevant national activities and to participate in regional and international co-operation within the IHD programme. The knowledge of the world's water resources as an independent professional option and facilities for the training of hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade, and, following the recommendations of Member States, Unesco, in 1975, launched a new long-term intergovernmental programme, the International Hydrological Programme (IHP), to follow the Decade.

Although the IHP is basically a scientific and educational programme, Unesco has been aware from the beginning of a need to direct its activities toward the practical solutions of the world's very real water resources problems. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the International Hydrological Programme have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multipurpose utilization and conservation of water resources to meet the needs of economic and social development. Thus, while maintaining IHP's scientific concept, the objectives have shifted perceptibly towards a multi-disciplinary approach to the assessment, planning, and rational management of water resources.

As part of Unesco's contribution to the objectives of the IHP, two publication series are issued: "Studies and Reports in Hydrology" and "Technical Papers in Hydrology". In addition to these publications, and in order to expedite exchange of information, some works are issued in the form of Technical Documents.

BACKGROUND

Besides the expected benefits, water projects may also have unfavourable effects on the hydrological regime, on the environment in general and on health and living conditions of the populations concerned. Rational water management should include taking into account both the favourable and unfavourable effects. This implies the assessment of the socio-economic and environmental impacts of changes in the hydrological regime.

The influence of man on the hydrological cycle and the impact of water projects are priority areas for both UNEP and Unesco in their respective water programmes.

The water resources programme of Unesco is centred on the International Hydrological Programme (IHP). The influence of man on the hydrological cycle has been a priority area since the start of the International Hydrological Programme in 1965. This section covers scientific studies of the influence of man on the hydrological cycle, including water quantity and quality. The activities of man are considered to include direct action such as land-use changes, consumptive use of water, physical operations on river systems, addition of contaminants of various kinds, as well as those of a more indirect nature such as, for example, man-induced climatic changes. These studies also include the effect of changes in the hydrological cycle on social, environmental and ecological aspects relative to water resources.

The studies executed in the framework of the IHP will result in the synthesis of existing knowledge, guidance material for the execution of national studies, teaching notes, and public information material. Publications issued in this area include:

- "Man's Influence on the Hydrological Cycle" (with FAO)
- "Hydrological Effects on Urbanization and Industrialization on Water Resources Planning and Management"
- "Casebook on Methods of Computation of Quantitative Changes in the Hydrological Regime of River Basins due to Human Activities"
- "Aquifer Contaminants and Protection"
- "Hydrological Problems related to the Development of Energy"
- "Study of the Relationship between Water Quality and Sediment Transport"
- "The Hydrological Regime as Influenced by the Drainage of Wetlands"
- "Investigation of the Water Regime of River Basins Affected by Irrigation"

and more recently:

- "Hydro-environmental Indices, a Review and Evaluation of their Use in the Assessment of the Environmental Impact of Water Projects".

UNEP's water programme is focused on the Environmentally Sound Management of Inland Water (EMINWA). This programme is designed to assist governments to integrate environmental considerations into the management and development of inland waters, with a

view to reconciling and ensuring the development of water resources in harmony with the water-related (natural and man-made) environment throughout entire water systems. It contributes to a harmonious river basin development and to an environmentally sound regional development.

The main activities of the programme are:

- (a) to assist Governments to develop, approve and implement environmentally sound water management programmes in river basins by inland water projects;
- (b) to prepare a manual of principles and guidelines for the environmentally sound management of inland water;
- (c) to use the EMINWA inland water basins for demonstration purposes;
- (d) to train experts and implement an institution-building programme;
- (e) to make regular world-wide assessments of the state of the environment in inland water systems; and
- (f) to inform the mass media of the activities of the programme.

The first inland water project is the environmental management of the common river system of the Zambezi. The outputs of the international symposium on the impact of large water projects on the environment will directly contribute to the implementation of the EMINWA programme.

Objectives of the Symposium

The Symposium provided a good opportunity to exchange scientific knowledge and practical experience on the hydrological, environmental and socio-economic effects of large-scale water projects and in particular to review methodologies to assess the impacts before and after the implementation of the project.

The deliberations at the Symposium also led to recommendations to Unesco and UNEP to be taken into account in the elaboration of their future programmes in this area.

Proceedings

Copies of all papers were available for invited, registered participants.

Official Languages

The working languages of the symposium were English and French. Simultaneous interpretation into these two languages was provided.

Symposium Programme

The Symposium took place in Room II at Unesco Headquarters, 7 Place de Fontenoy, Paris 7.

Background

The programme of the Symposium was organized according to the five themes mentioned below.

There were approximately one hundred participants, whose names and addresses will be found in Annex I.

Themes

THEME I: Impacts of large in-basin water regulation and utilization schemes, including storage reservoirs, irrigation and drainage schemes, hydropower development and their implications upon water management policies.

THEME II: Impacts of large inter-basin water transfers and their implications upon water management policies. (With a special session on large versus small projects.)

THEME III: Impacts of many small schemes over a large area, such as small impoundments and their implications upon water management policies.

THEME IV: Methodologies for the assessment of impacts - international environment assessment in large international river basins.

THEME V: Public information and participation in the decision-making process in relation to large water projects.

Conclusions and Recommendations

1. Water resources projects needed for socio-economic development and the resulting environmental changes, are inseparable. Recent procedures for the planning of water resources projects and their assessment have promoted a better understanding of the conflicting nature of this problem and have contributed to improved decision-making as far as the development and management of water projects are concerned.
2. A large number of ecological, financial, social, economic and technical difficulties must be overcome. It is necessary not only to assess but also to manage the environmental impacts of these water projects on both a short and long-term basis. This can only be done if environmental considerations become an integrated part of the decision-making process.
3. It has been recognized that water resources projects have a dual objective nature, namely, to serve both socio-economic development and ecological-environmental development. These dual but sometimes conflicting objectives require trade-offs between them. To do this, alternative options should be considered at various levels of water resources decision-making (policy formulation, planning, design, construction, operation, maintenance, rehabilitation). To obtain the most appropriate option, a compromise between the dual objectives has to be made. This can be achieved by the environmentally sound management of water resources projects which should be oriented towards the establishment of a long-term, dynamic equilibrium between the water project and its environment.

4. The environmentally sound management of water resources projects should be implemented by an active interdisciplinary and intersectoral learning process. Representatives of various interest groups (socio-economic, ecological, technical, legal, local, regional and national) should be involved in the development and management of these projects. A proper institutional and legal framework should be established according to specific conditions. Monetary, measureable and qualitative aspects should be considered on an equal basis.
5. The interaction between water projects and their host river basins should be studied in depth. Both the basin-wide and the regional approach should be basic components of environmentally sound water management.
6. It was agreed that the success of a project is not necessarily related to its size. Both large and small projects have positive and negative elements depending on specific conditions. If the size of the project is one of the reasons for considering an alternative option, a comprehensive analysis of both small and large projects should be undertaken taking into consideration all social, economic and ecological aspects. Both types of project should be developed, planned, operated, maintained and rehabilitated in an environmentally sound manner.
7. To develop alternative options, several specific approaches were suggested. Water demand and consumption control was suggested as an alternative measure for water transfer. The local and regional beneficiaries and the people likely to be harmed by the project should be identified more precisely. Income distribution should also be considered. Land-use planning should be combined with water resources planning. Incentives to attract people to other areas can also be considered as alternative options. To develop and compare alternative options, the decision support system planned by IIASA has been supported as a possible tool for the environmentally sound management of water.
8. The costing of environmental impact management as identified by EIA should be integrated into the planning procedure. The application of this approach should be supported by environmental legislation especially in countries where such legislation does not yet exist. In this respect, the overall recommendation of the UN/ECE task force on the application of EIA was supported. It reads "EIA should be viewed as an integral part of the project planning process beginning with an early identification of project alternatives and the potentially significant environmental impacts associated with them and continuing through the planning cycle to include an external review of the assessment document and involvement of the public".
9. Continuous monitoring of the socio-economic and ecological aspects of water project development and management is strongly recommended with emphasis on pre-project and long-term follow-up monitoring.
10. The UNEP/Unesco draft methodology on integrated environmental evaluation of water resources development was considered to be appropriate for evaluating the state of environmentally sound management of water projects and river basins. It was recommended that Unesco and UNEP should finalize this draft methodology and support its further development and application.
11. Better co-operation and understanding between specialists from various disciplines dealing with water projects and problems are needed and strongly recommended.

Background

12. It was recommended that a systematic review of existing methods of evaluating all possible interaction between water management activities and environmental components be undertaken, for example, in the form of a matrix and referring to existing literature.
13. Although in most cases it is not possible or advisable to transfer methodologies for public information and participation from one social environment to another, it is recommended to collect and exchange information on national experiences.
14. As no environmentally sound planning and management is possible without the active positive involvement of professionals including planners, UNEP and Unesco are recommended to continue and expand their activities related to the incorporation of environmental aspects in the formal education and post-graduate training programmes of engineers and planners. This education should not only relate to the scientific and technical aspects but also to the social and ecological ones.

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THEME I

**IMPACTS OF LARGE WATER IN-BASIN REGULATIONS AND UTILIZATION SCHEMES,
INCLUDING STORAGE RESERVOIRS, IRRIGATION AND DRAINAGE SCHEMES,
HYDRO-POWER DEVELOPMENT AND THEIR IMPLICATIONS FOR WATER
MANAGEMENT
POLICIES**

PAPER 1

FORECASTING THE EFFECT OF SADAM RESERVOIR ON TIGRIS RIVER WATER QUALITY

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and

Lath N. Fathallah²

1. Introduction

1.1 Historical background

Iraq is a country in which nature has provided all the conditions for successful agriculture during many thousands of years. The famous Namrud Dam and the Nahrawan Canal System bear witness to the high level of advancement in irrigation 3000 years ago. After the 13th century, most of the irrigation works in the country were either destroyed or abandoned.

1.2 Present situation

The agricultural production in Iraq does not meet the demand of the increasing population because of low productivity of agricultural lands caused by a continuous increase in the salt content of the soil especially in the southern part of the country. The reclamation of the salt-affected lands and the rapid increase in the number of land reclamation projects in recent years will lead to the use of large quantities of water especially in the Tigris basin. The need for full utilization of water resources will arise in the near future to meet the needs of an increasing population, an increased standard of living and the development of industries.

1.3 Present action

At present, little or no attention is given to the quality of water. The greater portion of the drainage water from the irrigated lands is discharged into the two rivers, especially the Tigris. The water stored in the reservoirs which is used for irrigation purposes has a high salt concentration due to high evaporation. The increased salt content in surface waters will make the water less suitable for agricultural use. More advanced practices will have to be adopted in order to conserve surface water quality and quantity. These include paying

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greater attention to the problems of choice of irrigation methods, adequacy of drainage and soil management techniques most appropriate to the situation.

1.4 Construction of Saddam Dam

A large dam has been constructed in the upstream reach of the Tigris River. It is a multipurpose project which stores water for irrigation during dry periods. It generates electricity, prevents floods and could be a major attraction for tourists and holidaymakers.

Sadam Dam will store a large volume of water and create a lake covering several hundred square kilometres. Some large irrigation projects will convert rainfed agricultural land to irrigation.

The impact of Saddam Dam on the environment is expected to be of great significance. Water quality will be effected most of all. In this study a forecast of the future quality of the Tigris River water is made following a broad investigation of present water quality data.

2. Water Uses in the Tigris River Basin

2.1 General uses of water

The largest consumers of surface water in Iraq are the agricultural and industrial sectors, as well as for domestic uses. The most detrimental effects result from the disposal of the agricultural, industrial and domestic waste directly in the river and a general absence of wastewater treatment.

All efforts are being devoted to the control of the pollution problems caused by urban centres, such as domestic liquid wastes, solid wastes, and stormwater runoff. The industrial pollution problems received little attention until recently.

Agricultural pollution and the related environmental impacts have received little attention in Iraq. This can perhaps be attributed to the fact that it is often believed that control of pollution due to agricultural activities is difficult.

The type of pollution resulting from agricultural waste was ignored for the reason that agricultural practices developed slowly over a long period of time. However, remarkable changes have taken place in the last few years in the field of agricultural production methods. This has been made possible by the reclamation of the salt-affected soils in Iraq and the cultivation of the reclaimed lands, the establishment and operation of modern and well-organized irrigation projects throughout the river basin, the operation of new and well-designed drainage systems, the implementation of modern farm technology concerning land-use and farming methods, irrigation methods, irrigation efficiency, and the rise in the cultural and social standards of the Iraqi farmer. All these factors have contributed to the increase in the efficiency of agricultural production, and for this reason a variety of environmental problems have developed. The increase in agricultural production has had a detrimental effect on environmental quality and especially water quality.

2.2 Agricultural uses of water in the Tigris River basin and irrigation return flow

Only part of the river basin is devoted to irrigated agriculture. Such development is usually found near the cities and villages located close to the river.

Irrigated agricultural lands make a considerable demand on the water resources, especially of the Tigris River. Agricultural activities create significant water quality problems due to the use of pesticides, fertilizers and dissolved mineral salts which are present in irrigation return flow. There is also the problem of animal wastes from feedlots and dairy operations.

The intensive use of agricultural lands, especially in recent years results in large return flows and waste water of varying quality. At present, the irrigation return flow together with the return flow resulting from leaching operations are considered to be the most important sources of pollution as these are being discharged into the river system without any consideration being given to pollution problems (Al-Layla 1978).

The characteristics of the irrigation return flow differ from one place to another depending on the type of soil, fertilizer, cropping pattern, irrigation method and type of drainage. Generally, it contains the following constituents:

- dissolved solids picked up from the upper and deep soil layers of the irrigation areas;
- organic and decay matter from fertilizers;
- suspended matter washed away from the surface.

Domestic sewage in Iraq amounts to about 1.9 Gm³ (Al-Layla, 1984) the greater part of which is discharged into the river system without treatment.

Baghdad however is provided with a modern sewage system for collection, and the wastewater after treatment is discharged into the Diyala River. Several treatment plants are also being constructed for the complete treatment of wastes. The work done in Baghdad is a first step towards water quality management in the river basin.

At present, Baghdad and Mosul have storm drainage systems which cover a great part of the residential areas. The storm sewer also carries the illegal wastes from houses and commercial areas. The municipal wastewaters from Mosul, Tikrit, Amara and other small urban centres located on the river, are discharged into the Tigris without treatment, and the same is true of the other large cities such as Kirkuk and Baquba which discharge wastes to the tributaries. There are plans to put domestic sewage under full biological treatment by 1995. (M. Irrigation, 1975).

3. Experimental Work

The experimental part of this study consists of sampling and analyzing the Tigris River water to monitor the existing water quality at various points on the river course. The field work was performed during the period from September 1981 to August 1982. It was reasonable to presume that this period was representative of all the variations in river water quality and quantity (Fathallah, 1983).

Water samples were collected monthly from specified stations. The sample collection progressed from the middle of the month in the northern part of the river to the end of the month in the southern part.

The sampling points were selected so as to coincide with the streamflow gauging stations of the Directorate General of Irrigation. Some sampling locations were added in this survey,

such as Tikrit, Samarra, and Qurna to give a more complete view of the water quality variations along the river course.

The sampling stations were located sufficiently downstream of pollutant outlets to ensure dispersion over the cross-section of the river. Sampling stations were not located immediately below confluences. It is better to locate the station on the tributary just above the outfall. Otherwise the sampling station on the main river was located sufficiently downstream to ensure dispersion over the cross-section (Nemerow, 1974; Velz, 1950).

The parameters included in the chemical analysis of water samples were chosen in such a way as to serve as a guide to evaluate river water quality for possible agricultural purposes. These parameters were:

Electrical conductivity at 24°C, total dissolved solids pH value at 25°C, sodium, calcium, magnesium, potassium, chloride, sulphate.

Other useful parameters were determined from these laboratory results. These are used in irrigation water quality evaluation: exchangeable sodium percentage and the percentage of sodium ions among the cations.

A few samples were analyzed for boron in the Tigris River water, as this element is essential for plants, but is one of the most toxic if present in high concentrations.

4. Results and Discussion

4.1 River water analysis

The samples were analyzed according to standard procedures for the examination of water and wastewater (APHA, AWWA, WPCF, 1975).

Before discussing the chemical changes of water along the Tigris itself, it is of great importance to have some knowledge of the quality of water in the tributaries: Khabur, Greate, Zab, Lesser Zab, Adhaim and Diyala Rivers. Little information is available concerning the quality of these but the following table shows the range of TDS.

The mean concentration of the constituents at each station is presented graphically in Fig. 1. An examination shows that the variation in all constituents is characterized by small changes along the river from Phaish-Khabur to Samarra, but a steep rise in the content of most constituents is quite obvious after Samarra and proceeding towards Baghdad, Kut and Amara, the concentration reaching a maximum at Qurna.

The variation of TDS during the year of testing is shown on Fig. 2. Only four stations were selected for this purpose, considering the northern, middle and the southern regions of the Tigris River system. The same pattern was found for all the other chemical constituents.

Since Iraq is moving towards the complete use of its natural water resources to meet the increasing demands for food, domestic water and electricity, the quality of waste water will change with time. The increasing sophistication of society will lead to more pollutants being returned to the river system even if these may be considered insignificant at present.

Name of tributary	Range of TDS mg l ⁻¹
Great Zab	200 - 300
Lesser Zab	200
Adhaim	1 100 - 3 000
Diyala River (upper)	200 - 300
Diyala River (lower)	2 500

4.2 Expected variation of TDS in the Tigris

The expected development of agriculture will depend mainly on the availability of water especially in the Tigris River Basin. The plan to irrigate a large part of the rainfed agricultural lands located in the northern part of the river basin, is a good example of this development (Al-Layla, 1984).

The effect of the Sadam Reservoir on the river system (quantitative and qualitative) will be more evident as it is located on the main river, but the Tharthar Reservoir will affect the river system through the Tharthar-Tigris canal in which the flow is controlled and the discharge of the reservoir water into the river will not be continuous throughout the year but is released during certain periods as part of the overall water management of the river.

Taking this into account, the TDS variation, considering the available data on mineral pickup resulting from domestic and industrial water uses, can be determined for the river course. The effect of domestic and industrial water uses on the quality of the supplied water has been studied by determining the resulting concentrations of different constituents in the sewage effluent of the area supplied with domestic water. This has been done in the United States, and a national average range of increments has been established for most of the physical and chemical parameters of water quality. For example, the average increase in TDS is 100 - 300 mg l⁻¹ (Metcalf, 1972).

The expected TDS variation is shown in Fig. 3, and the following table presents values of salinity and the percentages of increase which were taken into account:

5. Conclusions and Recommendations

1. No consideration is given to the quality of the surface water, and to the quality of irrigation return flow in planning new projects, especially in lands with high residual salts.
2. The future increase in the salinity of river water will be significant, considering the expected expansion in water supply, irrigation, and industrial projects. The Sadam

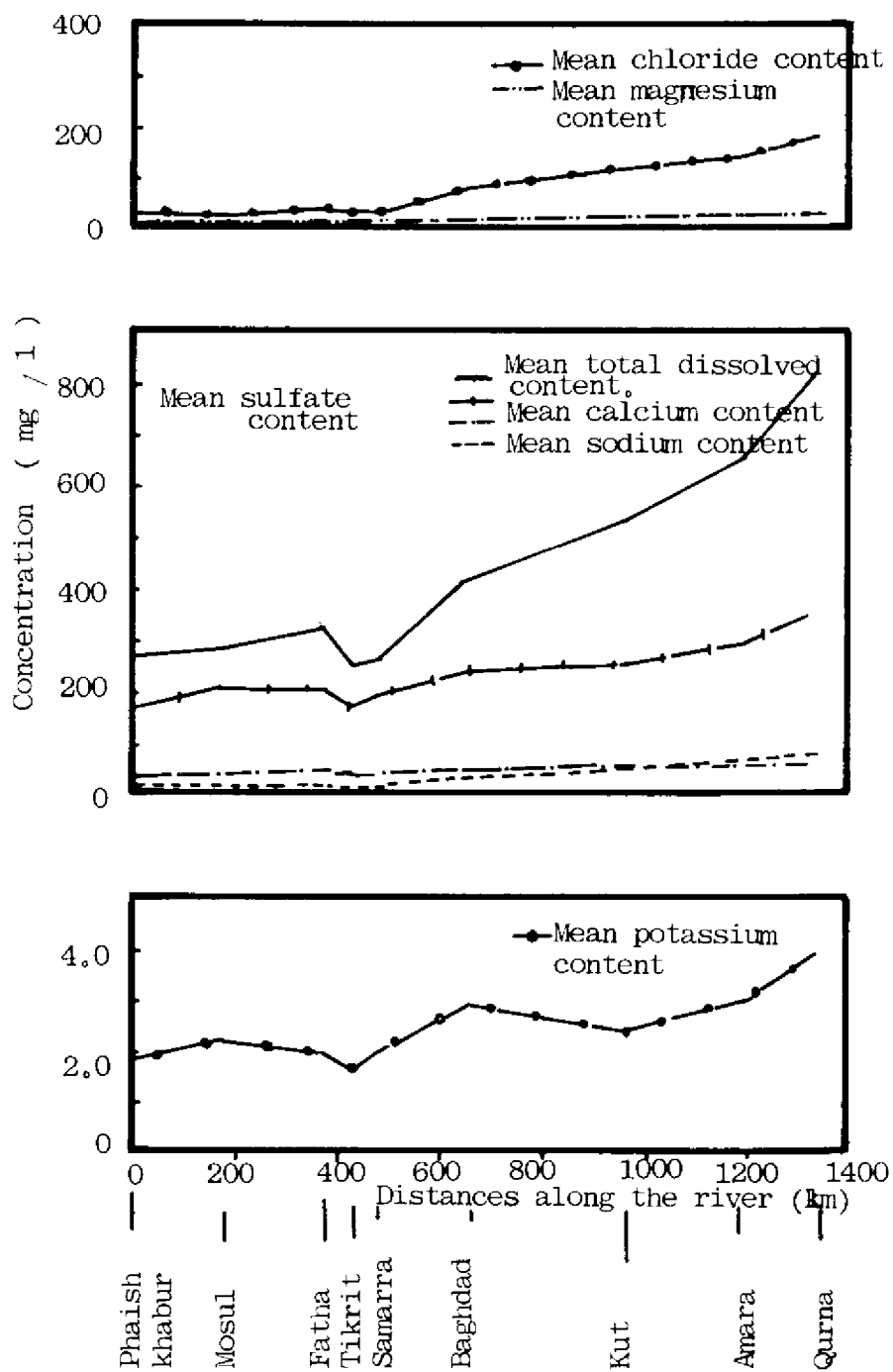


Figure 1.1: Mean solid contents in Tigris water

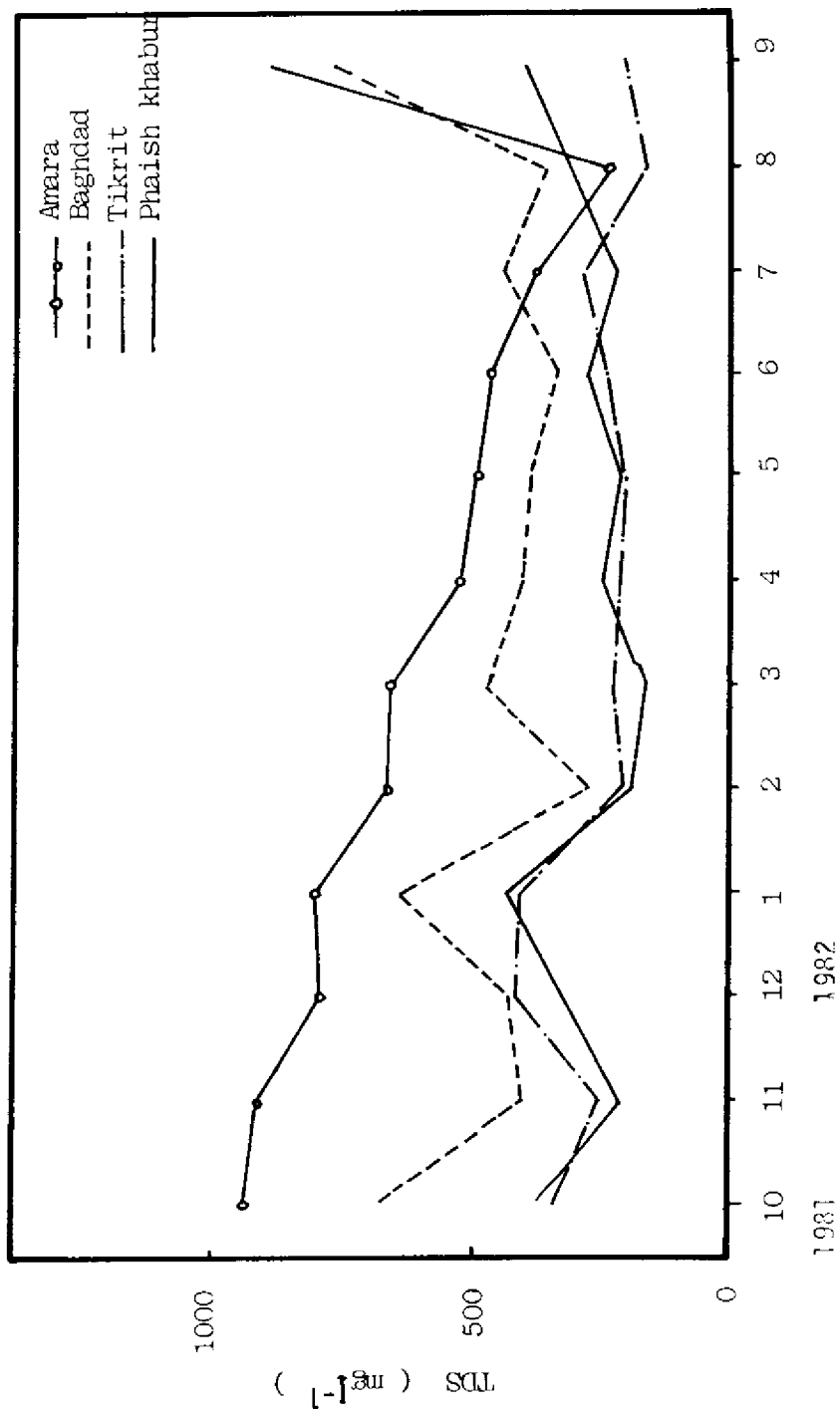


Figure 1.2: Total dissolved solids variation at four selected stations

Station	Present	%increase	Projected TDS values (due to water storage and domestic use)		
Phaish-Khabur (in flow to Sadam lake)	275	-	295		
Mosul (out flow of Sadam lake)	292	-	295	-	297
Fatha	327	-	297		
Tikrit	251	-	297		
Samarra (in flow to tharthar lake)	258	80	297		
Baghdad (out flow of tharthar lake)	464	15	535	-	553
Kut	531	22	636	-	638
Amara	644	28	778	-	780
Qurna	822		998		

Reservoir and the reuse of the Tharthar Reservoir water will increase significantly the salinity of the river water due to the high evaporation rates. The salinity is expected to increase at Sadam Dam from 275 to 295 mg l⁻¹ and from 295 to 320 mg l⁻¹ at Tharthar Reservoir.

3. The expected increase in water supply demand, due to increased standards of living of the Iraqi population, will lead to a large increase of salts in the river water at the main cities located along the river course.

To conserve the quality of the surface water in the Tigris River Basin, and to prevent deterioration of the river water quality, the following recommendations are made:

1. In planning new irrigation projects, careful consideration should be given to the quality of irrigation water and to the amount of residual salts contained in the soils of the project areas.
2. Water quality regulations should be imposed on the return flows of irrigated agriculture, using a point source of discharge (e.g. a pipe, ditch or other defined conveyance, whether natural or artificial).
3. It is essential to start monitoring the quality of the Tigris River water and of its tributaries as well as other specific discharges, to establish more complete data on water quality, which could be useful for the future quality of water studies.

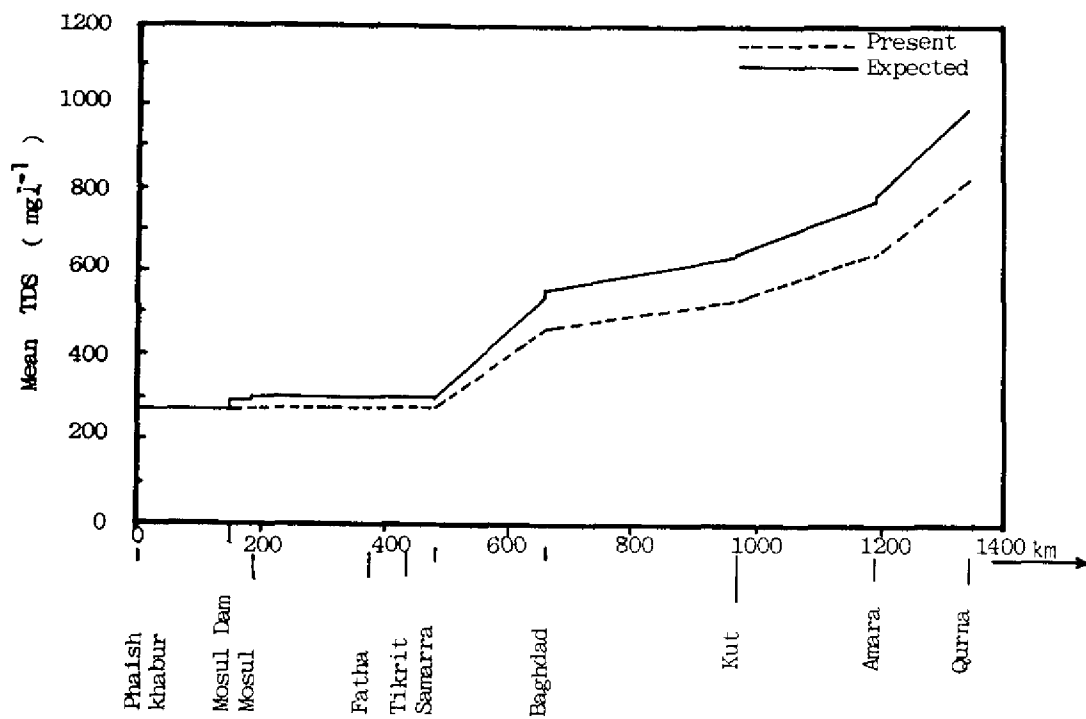


Figure 1.3: Expected salinity (TDS) variation along Tigris river

4. Careful consideration should be given to the movement of salts within a project area, especially in lands that have a high salt content.
5. Since Saddam Dam has been completed and that the lake will soon be fully formed, the following measurements are recommended:
 - a. The infiltration through the lake bed should be determined.
 - b. The evaporation from the lake surface should be estimated.
 - c. The runoff to the lake should be measured.
 - d. Continuous water quality monitoring should be instituted.
 - e. Meteorological data should be recorded along the Tigris River and its tributaries.

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PAPER 2

IMPACTS OF WATER-BASED DEVELOPMENTS ON THE COCHIN BACKWATER SYSTEM (KERALA, INDIA): IMPLICATIONS FOR WATER MANAGEMENT

*David Stephen*³

Abstract

This study examines water-based developments in the Cochin Backwater System (Kerala, India) and an assessment is made of the impacts of these developments on the environmental quality and aquatic resources. The geomorphological and hydrological features, ecological characteristics and the economics of aquatic resources are analyzed against a background of the growing demands for land and water resources from other sectors of the economy. Recent water projects for agricultural and industrial uses including large-scale land reclamations, construction of the Thanneermukkam Dam and several small impoundments to facilitate storage of freshwater and prevention of saline intrusion have resulted in significant losses of fishery and aquaculture resources of considerable national importance. The emerging multiple resource use situation is examined in the context of an environmentally sound watershed development and management framework. Based on an overall assessment of the adverse impacts of these developments and given the general lack of horizontal communication between development planners and users of water resources, it is clear that without the urgent enactment of suitable resource development and management policies, the capacity of the resources of this backwater system to sustain an optimally balanced resource base will be greatly reduced or lost.

1. Introduction

Economic growth and development is often accompanied by increasing stress on natural systems and significant adverse effects on environmental quality. These impacts may result in direct or indirect economic losses by certain sectors. The dilemma is how to conduct development activities in a manner that preserves the long-run productivity of natural systems for sustained economic development and at the same time minimize if not completely prevent deterioration in environmental quality. It is possible to achieve this to a large extent only if a political/public mandate for environmentally sound planning and management can be established. The case of the Cochin Backwater System (Kerala, India) illustrates such environmental impacts and underscores the need for conservation oriented water resources management, under a comprehensive environmental protection policy.

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This study examines recent water-based developments with emphasis on water impoundments and land reclamation projects in the backwater region. In addition, an assessment is made of the impacts of these activities on the living aquatic resources and environmental quality. The resulting comments and recommendations based on a critical appraisal of the water resource situation. The data presented here form part of a dissertation on the management implications of the impacts of agricultural, industrial and urban developments on the aquatic resources of the Cochin Backwater System (Stephen, 1985).

2. The Cochin Backwater System

2.1 Background information

The Cochin Backwater System is an extensive brackish waterbody in the common deltaic region of several rivers that drain the Cochin Watershed (Fig. 1). The backwaters are bound by barrier islands and have numerous interconnecting canals. There have been considerable discussions on the geological history and formation of the Cochin Backwater System, important among these are the more recent geomorphological, geophysical and hydrological changes, such as exposure and inundation of barrier islands, shoreline changes, coastal erosion, floods, drainage patterns, sedimentation process and tectonic events (GSI, 1980). Historical records show that the harbour of the ancient port at Muziris (located at the northern outlet of the Periyar River) was periodically flooded followed by heavy silt depositions. By 1340, the port had become unfit for navigation, but the timely occurrence of an earthquake in 1341 caused the narrow outlet at Cochin to greatly widen and form a natural harbour. These underlying natural processes are important to a better understanding of what human activities might entail.

The Cochin Backwater System is ecologically complex and exceptionally productive and therefore sensitive and stress vulnerable. Development activities (land and water based) in such an ecotone environment will require exceptionally vigorous planning and management. It should be noted that there are some primary and secondary uses and more importantly that there are some ecologically conditioned primary uses as well (eg. fisheries and extensive/semi-intensive aquaculture). The situation in the Cochin Backwater System, due largely to a lack of comprehensive regional planning and water resources management, shows many competing and conflicting water uses. In this multiple resource use situation, as is often the case, ecologically conditioned uses are threatened to the point of exclusion.

2.2 Aquatic resources: ecologic/economic considerations

The Cochin Backwater System is the largest brackish waterbody in Kerala and the third largest in the country. The extractable aquatic resources are primarily fishery resources of considerable national importance and significant deposits of limeshell (fossil). These waters favour small-scale fisheries based on traditional fishing methods and fish-shrimp farming. It is estimated that the total annual take of finfish ranges from 15 000 to 20 000 tons. Shrimp production from capture and culture operations is estimated at over 10 000 tons, about 80 percent of this coming from seasonal culturing in rice fields. Almost all the shrimp is exported, mostly to Japan and USA along with trawl catches from the adjacent sea. A base level estimate of the contribution of shrimp to foreign exchange earnings is a significant US\$15-20 million, whereas trawl catches from the adjacent sea contribute much less.

Most of the State's inland fisherfolk population is scattered around the backwaters in about a hundred villages. There are more than 20 000 households with a total population of about 124 000. They operate about 3 000 Chinese dipnets, 8 000 stake nets, 700 cast nets

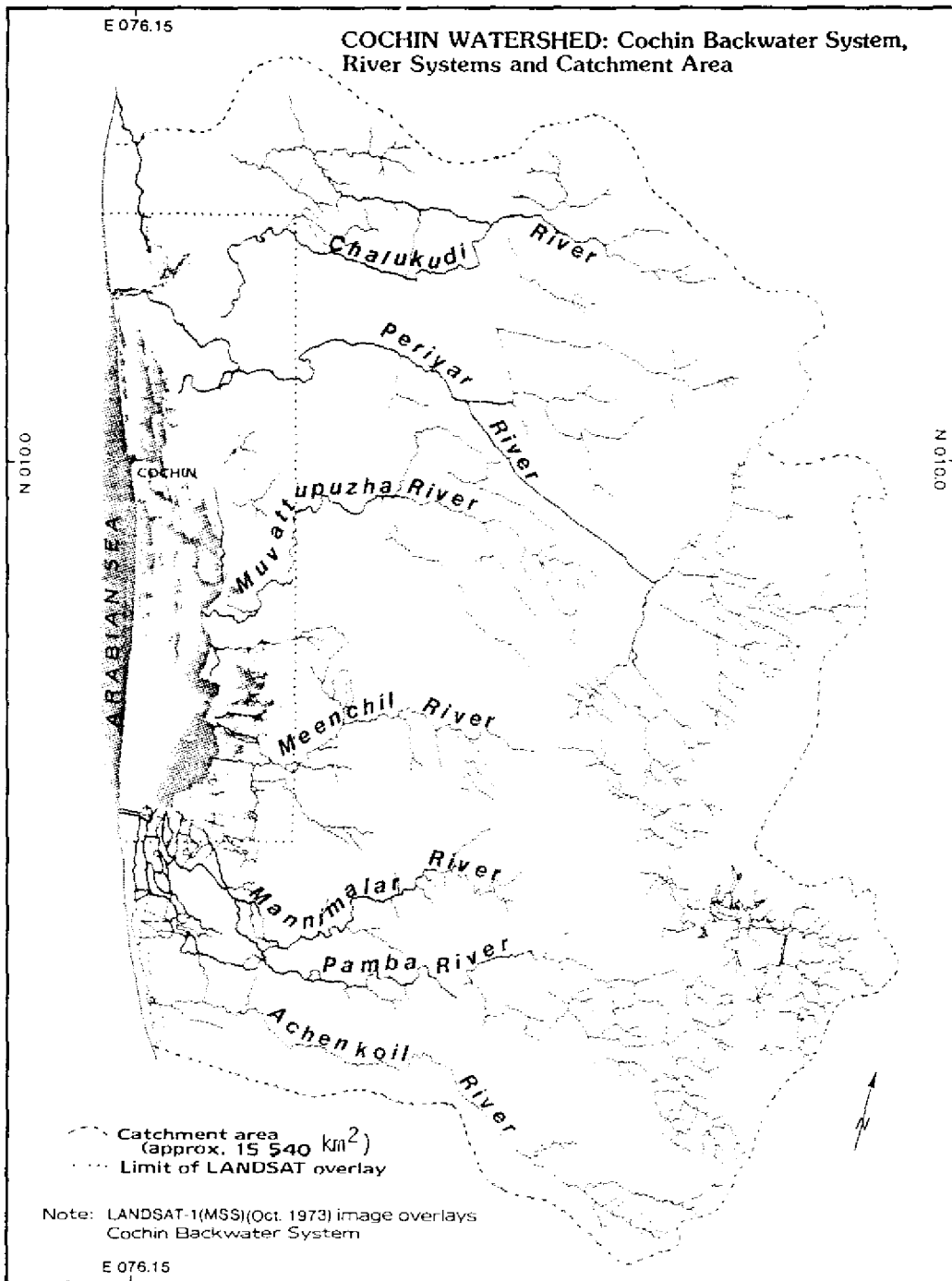


Figure 2.1: The Cochin Watershed and the Cochin Backwater System (Kerala, India)

and numerous seines, gillnets and traps. According to licences issued by the state for shrimp farming, about 1 000-1 300 farmers may be involved in farming about 4 000-6 000 ha each season (April 15 to November 15). The traditional method of shrimp farming involves the conversion of lowlying rice fields into shrimp ponds after the single monsoon crop of rice has been harvested. The natural advection of shrimp seed into the backwaters is engineered to stock these enclosures through a system of canals and sluice gates (Kurien and Sebastian, 1982).

Although a majority of the fisherfolk derive their income from fishing and related activities, some seek part-time employment in other sectors of the economy to supplement their income. More than 50 percent of the households have annual earnings of less than Rs. 1000, about 38 percent have annual incomes between Rs. 1000 - 2000 and only about 3 percent have incomes above Rs.3000 (GKDF, 1982). The State government has tried to address the problems of low income among fisher folk through a number of programmes and development projects. Much of this effort has been directed towards expansion and intensification of shrimp farming with the dual objective of improving their socio-economic condition and augmenting shrimp exports. The State has indicated a budget outlay of over US\$20 million in the Sixth Five-Year Plan (1978-83) (GKDF, 1983).

The importance of fishery resources in the welfare of the fisherfolk of the backwater region cannot be overstated. Furthermore, about 90 percent of the population in the region eat fish. Fish forms 70-80 percent of the protein intake in the state. Hence the need to develop the fishery resources of the Cochin Backwater System. However, the fisheries sector is not without problems inherent to open-access common property resources. These include over-exploitation of fish and shrimp stocks, conflicts and competition between fish farmers and net fishermen and a general lack of enforcement of existing, though inadequate, regulatory measures. Apart from the economics of aquatic resources, these backwaters are ecologically vital to the fishery along the coast. The Cochin Backwater System forms spawning and nursery grounds for a number of migratory species of fish and shrimp. In fact, shrimp that escape capture in nets and impoundment in ponds migrate back to the sea where they sustain a large trawl fishery along the penninsular coast. Therefore, the ecological stability of Cochin Backwater System is essential to the overall success of the fisheries economy along the coast. However, the greatest threat to a sustainable fishery and aquaculture practice in the Cochin Backwater System comes from extrinsic sources, stemming largely from agricultural, industrial and urban water use.

3. Impacts of Water Based Activities and Projects

The agricultural and urban-industrial bases in the backwater region rely heavily on the freshwater of the upstream reaches of rivers and their tributaries. Groundwater in the region is brackish and hence cultivation depends on the monsoon rains and their duration. The urban-industrial complexes of Cochin and Eloor meet their water requirements from the freshwater zones of the Periyar River. The Cochin-Ernakulam city complex had a population of 1.4 million in 1981, which is expected to more than double by 1991. The riparian population as a whole is expected to reach 5 million by 1991, with about a third of this population spread out in rural or semi-urban areas of the backwater region. Thus, there will be an increasing demand for new land and freshwater resources in the region. The impacts of land reclamations and water impoundments for agricultural and industrial uses in the region will be examined in the following sections.

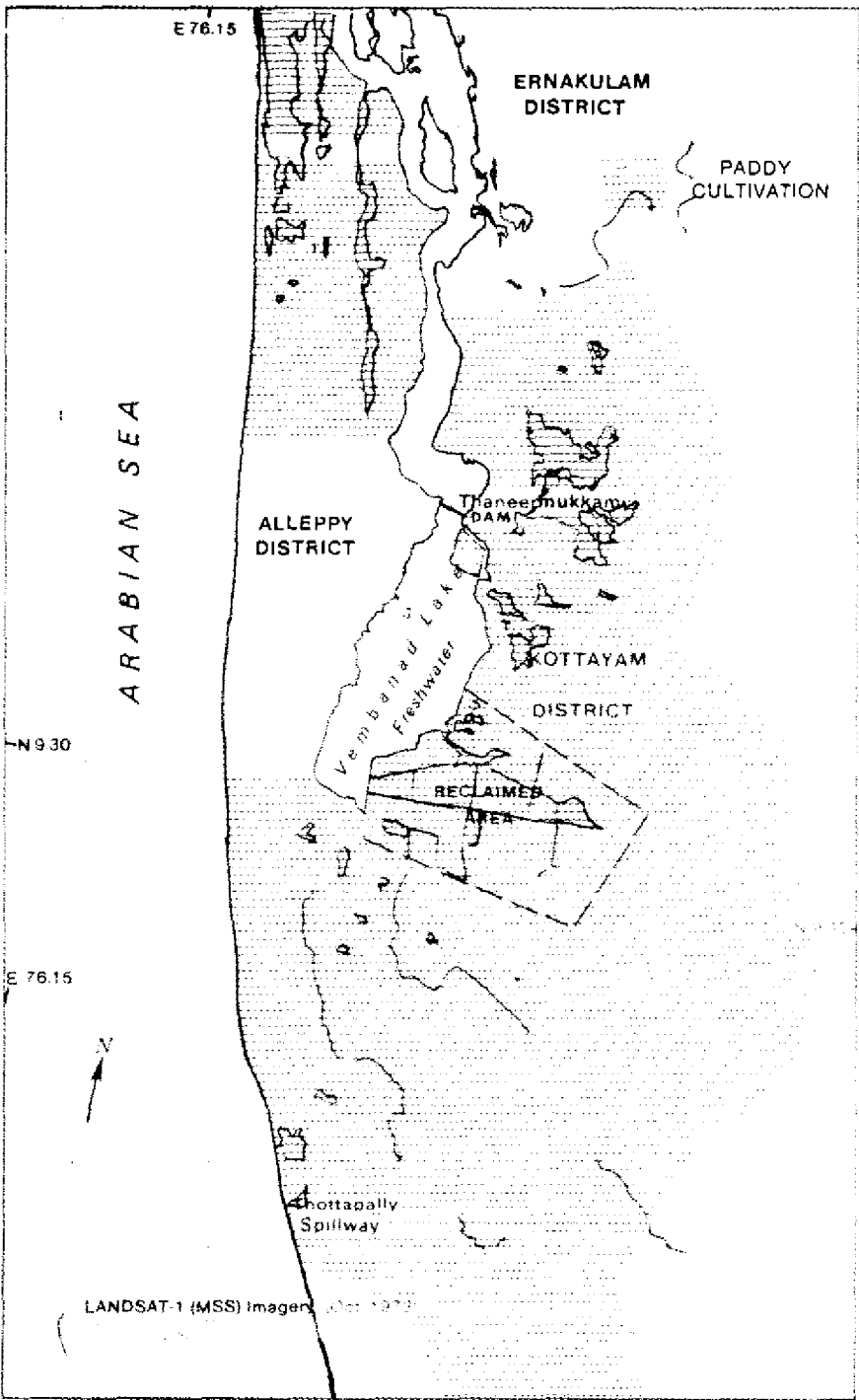


Figure 2.2: The Thaneermukkam Dam and rice cultivation in the Cochin Backwater Region (note extent of reclamation)

3.1 Land reclamation and the Thanneermukkam Dam

Agricultural practice in the backwater region is primarily rice cultivation and the vast areas of wetlands in the region are all under rice. The area surrounding much of the Vembanad Lake, called Kuttanad, is distinguished as "the rice bowl of Kerala". The geographical area covered by Kuttanad is over 1 630 km² of which about 800 km² is wetlands. Rice cultivation here is unique because these areas lie below sea level (1.2-1.8m) and in the past were submerged under saline waters for the greater part of the year. Therefore, rice cultivation had to be restricted to the monsoon period when river discharges maintain freshwater conditions. However, under these conditions, it is estimated that over 33 000 tons of paddy were lost each season due to crop damage from floods and saline intrusion.

Rice shortages in the region were mainly responsible for large-scale reclamations of shallow margins of the backwaters, particularly in the Kuttanad. It is worth mentioning that reclamations may have been initiated as early as 1834 as shown by tax records (GKKEC, 1972). In any case, by the beginning of this century about 2 200 ha had been reclaimed for rice cultivation. In 1903 reclamation was stopped as it was feared that it would have adverse impacts on Cochin harbour. However, after an assessment that indicated no such impacts, reclamation was resumed. By 1945 about 10 000 ha had been brought under rice cultivation. Yet another 640 ha were reclaimed by 1961 through a government project at a cost of US\$ 250 000.

Under the "Kuttanad Development Project" a total of 79 villages were adopted for planned agricultural development. Government efforts were designed to alleviate two of the most serious problems in cultivating rice here: floods and saline water intrusion. The strategy was to construct a spillway at Thottappally (commissioned in 1955) to discharge flood waters and to build a dam at Thanneermukkam to prevent the entry of saline water to rice farming areas up-river, to the south, thus changing the water below the dam from brackish to freshwater (Fig. 2).

The Thanneermukkam dam was initiated under the Second Five-Year Plan (1960-65) but was not commissioned until 1973. The revised cost of the dam in 1971 was estimated at about US\$ 4.5 million, which is five times more than the original estimate. The dam is 1 500m long and connects two narrow points in the lake between Thanneermukkam and Vechoor. It consists of two parallel rows of rubble-dumped walls filled with earth in between. The dam has a height of 1 m above sea level and has 430 steel-shuttered gates. There is a 12 m wide road with bridges over the three locks. The twin locks on the Thanneermukkam side and the single lock on the Vechoor side permit boats to pass through.

No elaborate environmental or socio-economic impact assessments were made before construction of the dam was approved. Apparently, the critical food shortages at that time made such projects imperative. Nevertheless, according to the project reports, the site for the dam was selected on the basis of two important considerations:

1. A barrier at Thanneermukkam would protect all the reclaimed land to the South from saline influence;
2. A barrier here would not affect northern areas where a more flourishing fishing industry exists. The dam and the spillway were expected to facilitate not only the regular monsoon crop but also an earlier crop or even a third crop of rice. But

unfortunately, in recent years farmers have been reluctant to plant even a single crop of rice.

In spite of the facilities provided for improving production, farming in the reclaimed lands is beset with numerous problems. These problems may be grouped under natural hazards and economic constraints. Among the natural hazards, floods, salinity, acidity of soils, pests, diseases and weed infestations are important. Though the Thottappally Spillway mitigated to some extent the severity of monsoon floods, damage still occurs due to breaching of bunds during floods. Compounding these problems are the high acidic conditions of these soils and the toxic salts contained in them, which require the use of lime as a soil conditioner. With the adoption of intensive farming methods the incidence of pests and diseases has become acute. The large quantities of insecticides used for crop protection run off into the lake. Weeds such as Water Hyacinth (*Eichornia*) and the African Payal (*Salvinia*) choke up rice fields, waterways and extensive areas of the lake. Before the construction of the dam, these weeds were killed by saline waters and did not pose a problem to farmers and boat operators.

In view of the physical features of these lands and all the additional management costs taken together, rice cultivation involves higher risks and higher capital costs than elsewhere. In fact, only government subsidy, money lenders and bankers have made rice cultivation possible. However, in recent years, labour disputes and declining rice procurement prices are forcing farmers to plant cash crops such as coconuts. It seems likely that the price of rice will continue to fall because of cheaper and higher productions elsewhere in the state and country. The economic viability of rice cultivation would depend on government price support for rice and continuation of other subsidies (eg. electricity). Such measures would mean a transfer of public funds in favour of rice cultivators (land owners) and discrimination against the larger population of low-income labourers and consumers. Kuttanad has a very high labour force of nearly a million people. Declining wages have already led to labour disputes in the region. Hence, alternative forms of using the reclaimed lands and providing employment must be seriously considered.

Land reclamations and the Thanneermukkam Dam have caused some hydrogeological effects as well. The dam physically separates the Vembanad Lake from the rest of the backwaters. The inflow and outflow of water through the dam can be regulated by operating the flood gates in the dam. These gates are kept closed to prevent brackish water from entering the lake. During the rainy season the lake serves as a freshwater reservoir, the excess flood waters being discharged by the Thottappally Spillway. The primary physical impact of the dam is that it reduces the bay area considerably for maximum tidal flow through the harbour outlet. The regulated discharge of flood waters during the monsoon causes heavy silt deposition in the lake, navigation channels of the harbour and other areas of the backwaters.

Recent observations of the Vembanad Lake clearly indicate several other adverse effects, some of these may be of a long-term nature. The surface water flow from the basin is restricted and this poses different hydrological problems:

1. The dam causes stagnation of water, which in turn creates waterlogging in the low-lying areas. The rise of the water table to the root zone of the plants has adversely affected crops including coconut plantations.
2. Stagnation of water accelerates the process of siltation and sedimentation of the basin. There are three rivers that bring down enormous quantities of silt and sediments.

Accumulation of sediments and silt may decrease the depth of the basin much more rapidly and in fact small islands have already emerged in the lake. Increased sediment load and volume of water may also have other adverse effects, such as a gradual subsidence of the basin; the Kuttanad basin is considered to be a "sinking basin".

3. The dam facilitated the expansion of the water surface area by causing submergence of shallow areas and inundation of new rice fields. The permanently enlarged water surface area may have local effects on the atmosphere, humidity and temperature and as such on local climate.
4. The sand bar on the western boundary of the basin between Thottappally and Ambalapuzha is very narrow and there is a danger of it breaching under heavy flood conditions.
5. Besides causing a drastic change in the salinity of the freshwater in the lake, the dam has caused an acceleration of leachates from the parent rock and soil and increases of the following: phosphate, zinc, iron, magnesium, ferric hydroxide and copper (GKKEC, 1972). There is also an increased concentration of leachates of fertilizers and pesticides and effluents from small industries along the shore.
6. Reduced streamflow due to construction of the Idukki Hydroelectric Dam upstream of the Periyar River and the increased runoff from deforested areas and rural areas in the watershed have all greatly increased the organic matter in the lake, producing organic acids and hydrogen sulphide in the benthic layers.
7. Ecological effects caused by the change in salinity and the presence of a physical barrier are seen in the profound changes in faunal composition. The consequent loss of fishery resources and development potential will be discussed below.

3.1.1 Impacts on aquatic resources

Before the construction of the Thanneermukkam Dam, the Vembanad Lake was generally brackish and it sustained typically brackish water species as well as migratory marine and freshwater species. A survey of fish and fisheries of this region indicated a diversified ichthyofauna and a rich fishery (Shetty, 1965). Important fishery resources were those of shrimp, mullet, pearl spot, hilsa, clams and the giant freshwater prawn.

The low saline regions of the lake are known to have supported a lucrative fishery for the giant freshwater prawn (*Macrobrachium rosenbergi*). An annual average landing of 400 tons of prawn has been reported. However, by the late sixties this fishery declined sharply and at present there is none. The chief cause for this tragic loss of the fishery has been the dam. Freshwater prawns require brackish conditions for spawning and the dam not only altered the salinity in their spawning grounds to freshwater conditions but also prevented access to brackish areas further North. The same explanation holds true for the loss of the hilsa fishery (*Hilsa* sp.) in the lake.

Marine shrimp fishing and culturing in rice fields has been stopped as the natural advection of shrimp is not possible with the dam in place. Mullet and other minor fishery species (eg. clams) have also been lost. The faunal composition has changed to more freshwater species eg. Tilapia and Black clams (*Vellorita* sp.) which are of no significant value. The clam fishery is being fully exploited by dredging operations to obtain limeshell (fossil deposits and live clams) for cement factories located nearby.

The original lake area was about 870 km² of which about 500 km² have been reclaimed. This drastically reduced the total habitat area available for spawning and feeding of aquatic organisms. A reduction in the fishable area also constituted a loss of fishing and aquaculture opportunities for the fisherfolk. It is an even greater loss in terms of potential fish available for local consumption and shrimp export for foreign exchange earning.

It is clear that post-independence food shortages in the region demanded *ad hoc* government projects to increase rice production. The construction of the Thanneermukkam dam and the Thottappally Spillway and the reclamation efforts were all partially successful in dramatically increasing rice production in this area. However, in less than a decade, the concurrent impact of the green revolution in India, mainly increasing production at lower costs, has made rice farming in the Kuttanad area an economic liability for the farmers. Given the favourable food situation in the country and state in the past decade, the continued maintenance of freshwater conditions in the Vembanad Lakemust be re-evaluated. Restoration of brackish conditions by opening the shuttered gates may revive the fishery. Furthermore, given the growing demand and higher prices for fish and shrimp, fish farming in the reclaimed rice fields as in the past, either seasonally or year-round, may provide a more lucrative alternative to rice cultivation. The socio-economic impacts and feasibility of such an undertaking should be carefully assessed.

3.2 Impacts of small water impoundments for industrial uses

The Cochin Port facilitated the establishment of an industrial centre based on imported raw materials in the Eloor area by the Periyar river. Availability of freshwater and access by waterways to the port made this an ideal industrial area. The rapid growth of this industrial centre has brought with it a concomitant increase in demand for freshwater in the upstream reaches of the river and a deluge of toxic effluents downstream. Increased silt deposition, land reclamations, greater extraction and diversion of water upstream have increased the zone of saline influence in the Periyar river. This has necessitated the construction of a number of bunds or weirs to prevent saline intrusion and to store freshwater, particularly during summer (Fig. 3). These physical barriers change circulation patterns, tidal flow, flushing rate and salinity characteristics of the backwaters. The most serious effect has been water stagnation and associated low dilution and poor flushing of effluents discharged by industries.

The problem of aquatic pollution is a serious one. The volume of industrial effluents produced daily in the Eloor-Kalamacherry industrial zone is about 250 000 m³, which is directly discharged into the backwaters without treatment. The major sources of effluents include fertilizer plants, chemical industries, an insecticides and a rare earths plant. Major chemical pollutants include acids, alkalies, suspended solids, free ammonia, ammonical nitrogen, insecticides (including DDT), dyes, chromium, mercury, zinc, other metals and unknown quantities of radioactive nucleides (Thorium and Uranium). While there are no direct discharges to the sea, about 2 000 m³ are discharged daily on land that run off into the adjoining backwaters. Each day about 100 000 m³ of industrial effluents from oil mills, petroleum refineries, fertilizer plant, shipyard and ship wastes all enter the backwaters in the central area of the Cochin Backwater System. In addition, a major source of organic matter for the backwaters derives from rural and urban domestic sewage waste waters. Cochin city alone produces over 2.55 Mm³ of waste water that is discharged daily without treatment into the port area.

There is evidence to show that increased freshwater diversion and storage by these impoundments have caused a build up of pollutants and organic matter in the backwaters.

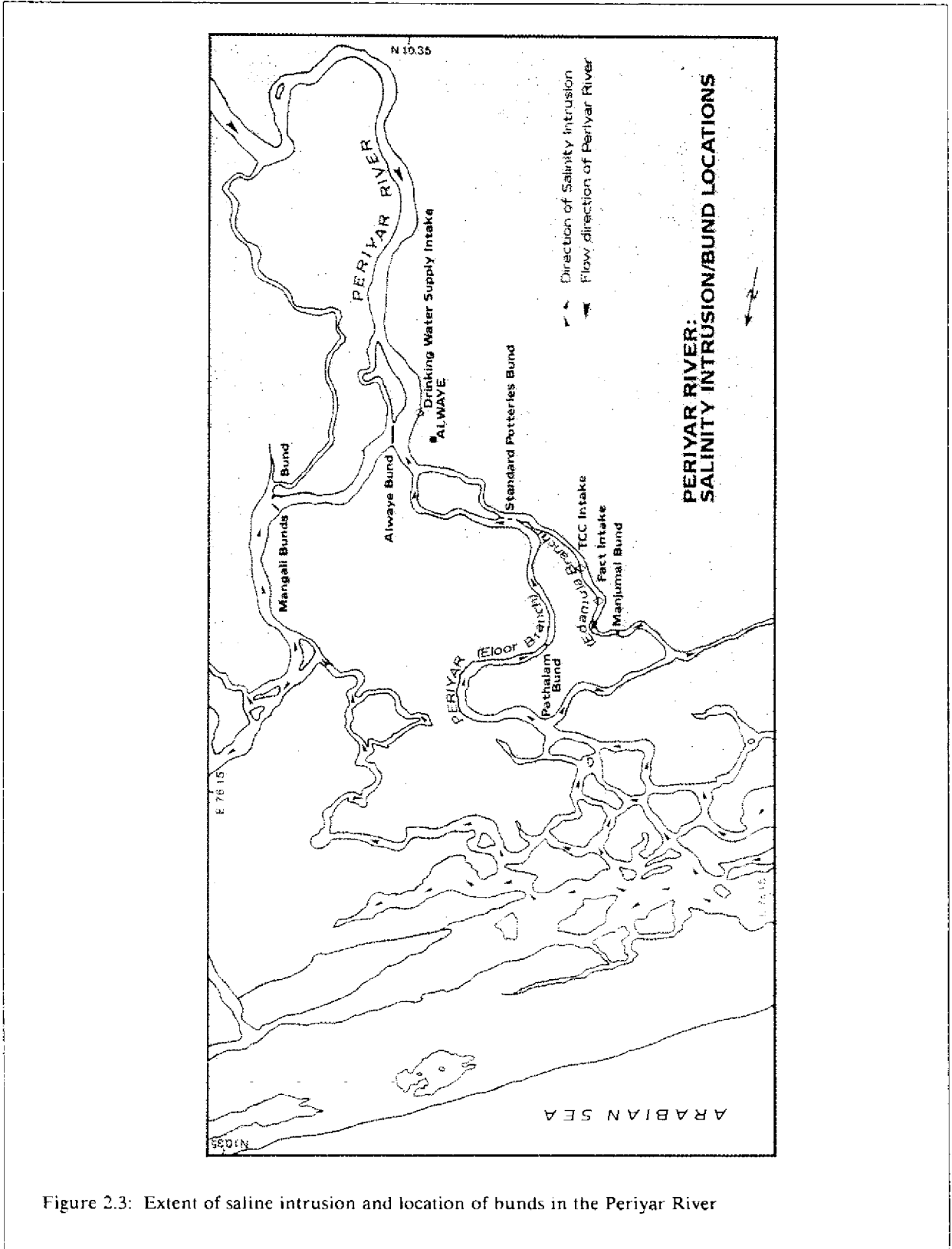


Figure 2.3: Extent of saline intrusion and location of bunds in the Periyar River

Studies of the bioconcentration of toxic substances in edible aquatic organisms (Lakshmanan and Nambisan, 1983) suggest that harmful levels have been accumulated in some species. In fact, in the last fifteen years there have been regular reports of fish kills in the backwaters (Silas and Pillai, 1976). Water-borne diseases, (gastroenteritis in particular is widespread) are becoming acute in the summer (Gore et al., 1979). Based on the extent of saline and tidal influence in the Periyar river, there is a risk of drawing polluted water from the Periyar River for domestic city supply (see Figure 3 for the location of domestic water supply intake).

Although the seasonal monsoon rains flush and cleanse these backwaters, the problem of pollution becomes more serious because of impoundments, particularly during summer when river discharge diminishes drastically. The geographic location of the industrial area and the drainage pattern of effluents result in pollution effects in extensive areas of the backwaters. Unfortunately, this includes the most productive areas for traditional shrimp farming which are located downstream of effluent flows (Fig. 4). With increasing water use and probable construction of more bunds in the Periyar River, the lack of adequate dilution and flushing can only worsen this situation. It is interesting to note that current fisheries development plans include improvements and expansion of shrimp farming capacity in this area. This clearly indicates a lack of appreciation of the magnitude of the pollution problem, an absence of foresight in planning and a general lack of horizontal communication between planners and water users. On-going reclamations for port and urban expansion may further alter drainage patterns. It is worth mentioning that Wellington Island on which the port facilities are located was once a small mudflat. The dredged material from the channels were dumped and consolidated to form this island.

It is clear that large-scale reclamations, several small impoundments and the Dam in the Cochin Backwater System have significantly altered the water surface area, the extent of brackish water influence and other hydrological characteristics. In terms of the aquatic resources, environmental quality and ecological viability, the impacts on fisheries, welfare of fisherfolk and public health are significant and demand immediate attention. In fact, according to strict hygienic requirements, extensive areas may be unfit for harvesting of edible forms of aquatic organisms. The loss of fishing rights, losses of fishable stocks and aquaculture areas and the potential loss of fishery development opportunities are tragic to those who directly or indirectly depend on these resources. But the social means to overcome these problems through integrated regional planning and the legal and institutional mechanisms to manage the water resources have not yet been well established. Those that exist carry little weight.

4. Implications for Water Management Policies

The extent, diversity and intensity of land and water uses in the Cochin Backwater System have reached levels that require urgent conservation oriented management practice geared to all its uses (Table 1). Without establishing water use policies and management practices, the growing demands for freshwater, new land in the waterfront and the necessity to dispose waste water in the backwaters will make fishery uses an increasingly difficult proposition. It is important to bear in mind that the adverse impacts of any water project depend on the geomorphological form of the water basin, the ecological characteristics and the carrying capacity (the potential of an ecosystem to provide products and services useful to human society).

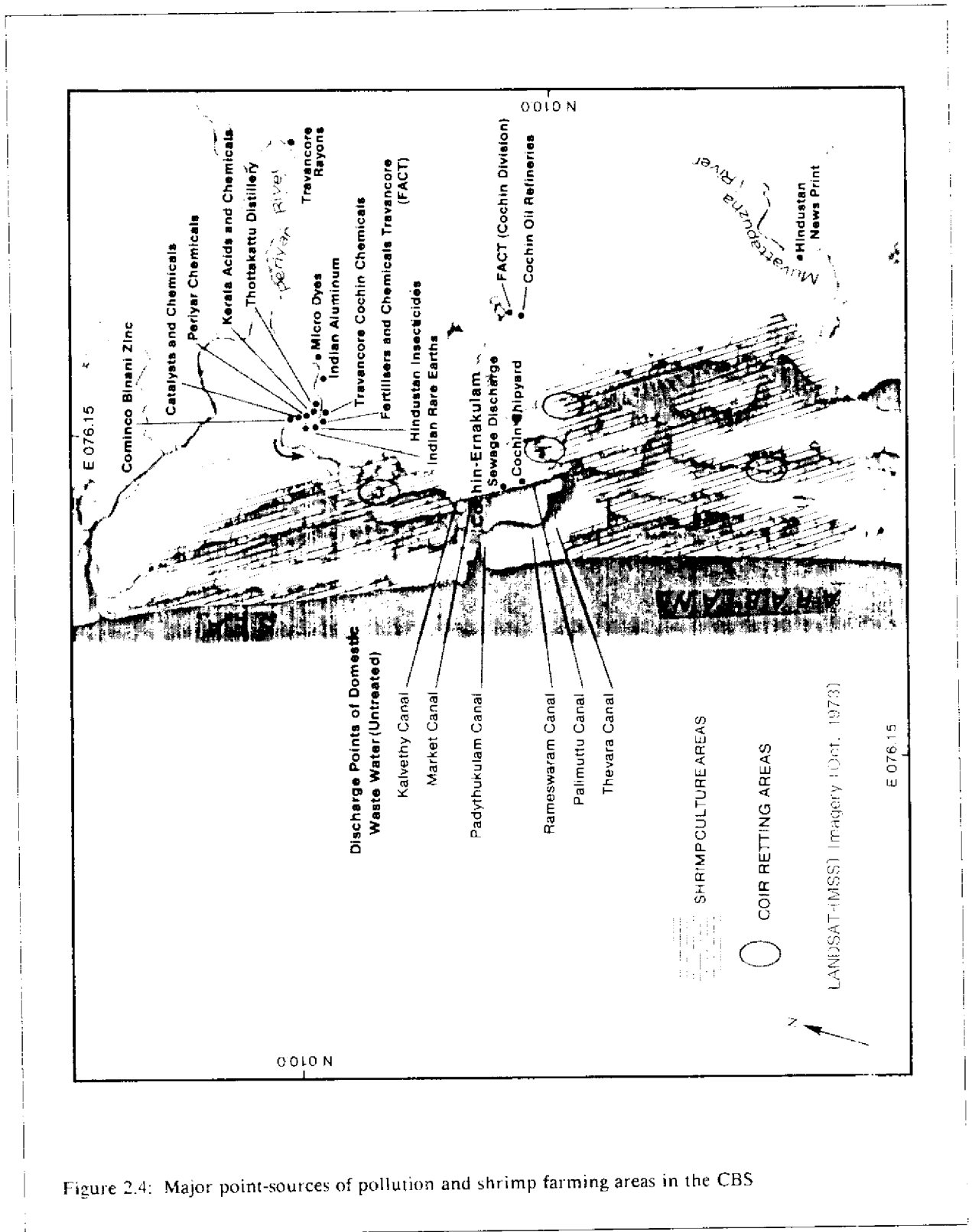


Figure 2.4: Major point-sources of pollution and shrimp farming areas in the CBS

Table 1
Adverse impacts of selected water uses on the aquatic resources and environmental quality of the Cochin Backwater System (Kerala, India)

	Land-based Activities			Water-based Activities			Remarks
	Industrial Development	Urban Development	Agricultural Development	Inland Water Transporation	Limeshell Mining	Coir Retting	
Physical	Construction of bunds for diversion and storage of freshwater	Land reclamation for housing and commercial uses	Land reclamations for rice cultivation. Construction of the Thanneermukkam Dam	Depeening of canals	Alteration of bottom topography. turbidity	Digging of wells	Affects circulation and flushing rates; significant reduction in water area
Chemical	Discharge of toxic effluents	Sewage discharge, runoff, dumping of solid wastes	Runoff-nutrients and insecticides; salinity changes	Bilge water discharge	Increased calcium content	Organic acids and gases	There are serious changes in the chemical characteristics of soil and water in certain areas of CBS
Bio-ecological	Aquatic Pollution-trace metals	Aquatic Pollution-organic matters	Aquatic Pollution-biocides; Physical barrier: Dam; Fresh-water Barrier	Pollution effects of oil	Increased turbidity and disturbed substratum	Organic Pollution	Residue of heavy metals in the aquatic fauna; deterioration of environmental quality
Fish and Shellfish Resources	fish/shrimp/clam mortality; loss of habitat	loss of habitat; environmental deterioration	loss of habitat; substantial loss of fishery resources in the Vembanad Lake	Negligible Impacts	Loss of Habitat	Loss of Habitat	Significant reduction in fishing area and fish/shellfish stocks
Fishing	Loss of fishing areas; Health hazards - fishing in polluted waters	Loss of fishing areas	Loss of fishing areas; low catches in the Vembanad Lake	Restriction of fishing in waterways	Loss of fishing rights in leased areas	Loss of fishing areas	Significant loss of fishing opportunity in the CBS

Stephen

Fish - Shrimp Farming	Pollution in growing areas; loss of potential growing areas	Pollution in growing areas (local); loss of potential growing areas	Loss of potential growing areas; Priority for rice cultivation- Land Utilisation Order of 1967	Negligible Impacts	Negligible Impacts	May affect fish/shrimp seed advec- tion into nearby ponds	Significant loss of aquaculture opportunity; Impacts on marketability of produce because of pollution in growing areas
Remarks	Present Industrial location policies may affect new areas of the CBS	Waterfront settlements may cause public health hazards; increase risk from subsidence/ erosion/ floods/tides	Land use regulations impose restrictions on fish farming period; these regula- tions also encourage land reclamation	Strakenet fishing in some canals may cause navigational hazards	Depletion and mortality of clams	Loss of aesthetic value	Order of priority for manage- action in the CBS 1.Aquatic pollution control 2.Export market- quality control 3.Prohibition of land reclamation 4.Maintenance of the phys- ical and chem- ical stability of the CBS

The concept of carrying capacity may be adopted as the basis for management policies with the fundamental goal of sustaining the carrying capacity at the optimal level. However, in practice, the complexity of the interrelationships and interactions within and between natural and social systems, particularly in a multiple resource use situation are such that optimal levels are rarely achieved. In addition, current development decisions on large-scale projects or projects that produce irreversible or long-term impacts may make optimization efforts difficult to achieve in the future, especially as necessities and priorities change. This is particularly true when such projects become ineffective for some reason as exemplified by the Thaneermukkam Dam. Nevertheless, it is believed that resource bases can be maintained at the highest level of health even while uses increase, if there is goal setting in advance, integrated and holistic planning and stringent management. It is also believed that trade-offs can be achieved without serious hardships through innovative management.

In the case at hand, absence of public policy on water resources and the lack of institutional mechanisms for management has led to many conflicting and competing uses. In the case of aquatic pollution, the Water (Prevention and Control of Pollution) Act, 1974 is not strictly enforced by the State Pollution Control Board. At present there are no laws to

adequately enforce protection, conservation or management of water resources or the environment in general. But recent policy pronouncements by the Government of India clearly reflect the political will for environmentally sound planning and management of development activities (GOI, 1980). The establishment of the Department of Environment and the stipulations for environmental impact assessments of large-scale projects are some of the recent government actions.

In the case of the Cochin Backwater region there is a need for an institutional body with adequate legal backing to oversee all water-based development and management. Such an arrangement will remove present problems of overlapping and sometimes inadequate jurisdictions and also facilitates better communication between sectors or water users. Above all, this would delegate authority and responsibility to one identifiable agency. As regards the current water situation, in addition to strictly enforcing pollution controls, water conservation must be practiced. Water impoundments must be engineered and regulated to maintain adequate flow downstream. The situation in the Kuttanad rice cultivation calls for restoration of brackish water conditions in the Vembanad Lake. Fortunately, the restoration of brackish conditions is feasible without the loss of the dam and the road upon it. Local development decisions on the future uses of the Cochin Backwater System are likely to be trade-off decisions as priorities change. The short- and long-term perspectives of trade-offs of environmental amenities and aquatic resources for non-fishery uses have to be carefully evaluated in each case. However, without the urgent enactment of suitable water management policies, the capacity of the resources of the system to sustain an optimally balanced resource base will be greatly reduced or lost.

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PAPER 3

RESERVOIRS OF THE WORLD AND THEIR ENVIRONMENTAL IMPACT

A.B. Avakian⁴

During the last three decades reservoir construction has acquired a global character. This is explained by a wide use of hydropower resources, intensive development of irrigation, industrial and municipal water supply, recreation and flood control. The total volume of reservoirs has increased ten times during this period. All in all, more than 30 000 man-made lakes are in operation at present. Reservoir construction has resulted in natural and socio-economic changes on 1.5 Mkm² of land, an area equal to that of several large European countries.

Reservoirs affect various elements of the environment, hydrological regime, aquatic and terrestrial ecosystems, sectors of the national economy, socio-economic conditions affecting the way of life of the people. All aspects of the problem are analysed here on the basis of reservoirs constructed in different regions of the world in different natural and socio-economic contexts.

A wide experience of medium and large man-made lakes has enabled the author to lay down the basic principles of construction and operation of these complex, dynamic and internally varied systems and their impact on nature and on the national economy.

The size of water management schemes and their environmental effect have increased rapidly during the 20th century in the USSR and elsewhere. (Table 1).

After the second World War reservoir construction acquired a global character. During the last three decades the world's reservoirs increased fourfold in number whilst their volume was multiplied by ten (35 in Latin America, 60 in Africa, 90 in Asia). All of the world's largest reservoirs were constructed during this period. More than 30 000 man-made lakes are in operation throughout the world at present. Their total volume exceeds 6 000 Gm³ and their surface attains 400 000 km².

The information available on reservoirs, especially small ones (with the volume less than 10 Mm³) is insufficient but large reservoirs (volume exceeding 100 Mm³) are well documented. Their volume amounts to 95 percent of the total volume of the world's reservoirs. The trend of the number and total volume of man-made lakes is shown in Table 2.

⁴ *Water Problems Institute of the USSR Academy of Science, Moscow, USSR.*

Table 1: Water management schemes of the world, 20th century

Year	Runoff Regulation Total Volume of Reservoirs (Gm ³)	Water Consumption (Gm ³)*	Area of irrigated land (Mha)
1900	15	400 270	40
1975	5 000	3 000 1 800	250
2010	10 000	6 000 3 000	600

*The first figure denotes total water consumption, the second - irretrievable water consumption

The useful volume of reservoirs amounts to 3 000 Gm³ representing a 25 percent increase in the stable component of the world runoff.

Reservoir construction has resulted in certain changes of natural conditions on 700 000 km² and infrastructural changes involving population resettlement and reorganization of the national economies on a land area of 1.5 Mkm².

The impact of reservoirs is most evident in the regions where they are constructed. Being the key to many water management problems, eliminating or attenuating certain economic conflicts, man-made lakes also create new conflicts between various branches of the water economy, depending on the character and degree of runoff regulation, reservoir parameters, preparation of the submerged land, operating regime, time of construction, initial filling, etc. Conflicts also arise since man-made lakes have both positive and negative effects on every branch of the water economy, with the exception of hydropower production. Further extension of water management, construction of reservoir cascades and inter-basin transfers aggravate certain socio-economic conflicts. In any case, the construction of reservoirs is accompanied by a number of undesirable impacts on nature and on the economy of the territory where it is situated as well as on the areas downstream.

The environmental effect of man-made lakes is multiform: it can be direct or indirect, positive or negative. It can manifest itself immediately or many years after completion of the reservoir. The impact also depends on intrasecular and other climatic fluctuations that can attenuate or intensify the effect of the reservoir on climate, hydrological, hydrogeological and other processes.

Table 2: Number and volume of reservoirs of more than 100 Mm³ capacity

Continent	Up to 1900	1901-1950	After 1951	Total
Europe	9*	104	404	517
	3	122	491	616
Asia	5	46	526	577
	2	18	1 608	1 628
Africa	1	15	89	105
	0	15	870	885
North America	25	342	516	883
	9	344	1 325	1 678
Latin America	1	22	179	207
	0	18	623	641
Australia	-	10	63	73
	-	11	66	77
Total	41	539	1 777	2 357
	14	528	4 982	5 524

*The first figure denotes the number of reservoirs, the second - their total volume (Gm³)

Man-made lakes influence many aspects of the environment: hydrological regime both upstream and downstream the dam down to the river mouth, aquatic and terrestrial ecosystems, industrial undertakings and the socio-economic organization of human existence.

Reservoir parameters (surface, volume, depth, length, width, configuration, composition of rocks forming bed and shores, character of regulation, operation regime, regional climate) all have a great influence on the changes in natural processes and the direction of these changes both upstream and downstream of hydraulic structures. The character and scale of diurnal, weekly, seasonal and annual flow variations has a considerable influence on changes of the natural conditions downstream of the dam.

Reservoir construction aims at changing many environmental elements and is regarded as a means of transforming nature for the benefit of economic development. Among such planned transformations the following may be singled out:

- (a) improvement of hydrographic networks;
- (b) annual, seasonal, weekly and diurnal runoff redistribution and creation of water surfaces in the interest of various industrial processes;
- (c) concentration and accumulation of hydropower resources;
- (d) transformation of the hydrological regime for the purpose of rational land-use;
- (e) recovery of non-productive land for the purpose of the accumulation of water and creation of a more productive aquatic medium (fisheries and pisciculture);
- (f) attenuation or complete elimination of natural phenomena such as floods, mud-flows, sedimentation of lakes, etc;
- (g) improvement of natural conditions in the neighbouring area: milder climate, construction of a special network of water bodies etc.

At the same time the construction of reservoirs and their operation involves a number of undesirable and, as a rule, inevitable environmental changes. The most significant of these are:

- (a) inundation of land;
- (b) transformation of the reservoir bed and shores, degradation of riverbanks downstream and in some cases of sea coasts near the river mouth, resulting from the retention of solid flow by the reservoir;
- (c) raising of groundwater levels, resulting in waterlogging of productive land;
- (d) transformation and changes of soil and vegetation due to waterlogging and microclimate changes (intensification of winds, increased air humidity, etc.);
- (e) changes of fauna habitat in the river valley;
- (f) radical changes of aquatic fauna in the stream itself, the latter being transformed into a reservoir;
- (g) changes in water quality, resulting from the reduction of flow velocity, decrease of water self-purification capacity, excessive growth of blue-green algae and other factors.

Reservoir construction affects the landscape of river valleys and lakes. On big rivers water bodies 10 to 20 km wide and hundreds of kilometres long take the place of the river bed, the width of which does not exceed 1 to 3 km. The maximum depth of flood-plain reservoirs is 20 to 40 m. In foothill and mountain regions the depth may attain 100 m and even 200 to 300 m. The water surface area of large reservoirs is comparable to that of the biggest natural lakes.

Downstream of the reservoir the river valley landscape also changes, especially in the case of seasonal or long-term runoff regulation. The disappearance of flood peaks or the complete suppression of floods lead to the disappearance of flood-lands which dry up. Reductions of solid flow regime result in river-bed erosion directly downstream of the reservoir and in variations of sedimentation processes in deltas. Landscapes change considerably when the flow or the greater part of it is transferred to neighbouring basins.

Reservoir processes depend mainly on water circulation characteristics such as: constant output flows, intensive turbulent mixing, thermal stratification, water mineralization and aeration, as well as hydrochemical, hydrobiological and other peculiarities. Water circulation in reservoirs is subject to seasonal and long-term variations, depending on the volume of water, water use and other factors. Flow velocities in man-made lakes are some ten times less than in natural water bodies.

A complicated transformation of river water into a reservoir water body proper occurs whose main characteristics remain practically unchanged from season to season and from year to year as do the general characteristics of their distribution in the man-made lake.

Changes in hydrological regime (level, flow velocity, waves, sediment flow, etc.) in the upper and lower pools affect hydrological processes within the water bodies, leading to the formation of specific biotopes and biocenoses in reservoirs.

Reservoir interaction with the environment (particularly in the immediate neighbourhood of the reservoir, as well as in areas downstream of the reservoir) differs greatly from the interaction between natural rivers and the environment. These distinctions differ in plain and mountain regions with latitude and elevation.

Microclimatic changes occur due to the appearance of large water bodies as a result of the accumulation and return of much heat, and on account of the large water surfaces and other factors. They manifest themselves above the reservoir itself and in the adjacent areas. These changes include practically all the elements of climate: radiation balance, air temperature and humidity, wind regime, etc. The influence of large reservoirs affects a strip of land not wider than 10 to 15 km. The incidental effects on climate of the largest reservoirs can extend 30 to 60 km from the water edge, but is only significant from 1 to 3 km beyond the shores.

Changes of climatic and hydrological conditions raise the groundwater level in adjacent areas, causing waterlogging, changes in soil mineralization, and the formation of swamps. Vegetation changes include the appearance of phreatophytes. Animal habitats are disturbed, particularly those of aquatic and semi-aquatic mammals and water fowl. The scale of these environmental changes are appreciable: thus, the total area of lands subjected to waterlogging on the shores of reservoirs of the USSR is estimated at hundreds of thousands of hectares. Moreover, more than 50 percent of the reservoir shoreline is transformed.

Significant environmental changes are also observed in regions downstream of the reservoir, along rivers with regulated flow. On some rivers (Volga, Irtysh, Syrdaria, etc.) these changes threatened to become irreversible, but this was averted by the construction of special water release facilities from the upstream reservoirs (the Kiubyshev, Bukhtarma, Chardarin reservoirs). The water released restored to some extent the natural flood regime. For example, 70-130 Gm³ of water are sent annually down the lower course of the Volga to supply the Volga-Akhtuba flood plain in the interests of pisciculture (the amount of water depending on whether the year is dry or wet).

It has been ascertained in the last few years that man-made lakes influence tectonic processes, promoting the occurrence of earthquakes, increasing their frequency and intensity.

Reservoir construction entails serious changes in the quality of water and they have a considerable effect on almost all types of water use. Physical properties of water, its salts balance, concentration and nature of nutrient elements, as well as quantity and distribution of zoo and phytoplankton change when the reservoir is put into operation. Sedimentation of suspended solids, increase of water transparency occur during the process of river flow transformation in reservoirs. Dissolved oxygen concentration in all large reservoirs is favourable to all aquatic organisms, although it does not usually attain saturation. The absence of dissolved oxygen is observed at the water-sediment interface under conditions of marked thermal stratification.

At the same time when river water with a high concentration of nutrient elements flows into a reservoir, its capacity for self-purification is disturbed, particularly when an excessive growth of blue-green algae is observed (as compared to self-purification of river water). This is explained by a lower flow velocity in man-made lakes.

The effects of reservoirs on the environment have certain specific features.

Negative side-effects of reservoir construction can be classified in two groups: those inherent to the reservoirs themselves and those resulting from the violation of operating rules, the inopportune accommodation of certain national economic objectives to the new hydrological conditions, as well as possible deficiencies of design work.

The economic role and effectiveness of man-made lakes are determined primarily by their geographical situation on which depend many of their parameters, direction and scale of the development of various natural processes, measures concerning reservoir preparation, structure of the water resource system, operational regime, etc. The direct interdependence of various natural processes and technical and economic factors, manifests itself clearly in the case of the integrated use of man-made lakes. Therefore the geographical situation should be taken into account when selecting the optimum solution of water management problems. It is only on the basis of systems analysis that the economic role of reservoirs, can be correctly evaluated both as a whole and with respect to individual objectives. During reservoir construction and operation the multiple after-effects of projects should be thoroughly analysed, such as the choice of parameters, measures concerning reservoir bed preparation, etc. All large reservoirs should be considered from different standpoints:

- Storage of water, an essential resource for many branches of the national economy;
- Improvement or deterioration of water quality;
- Flow regulation involving modifications of the hydrological regime;
- Hydropower potential capable of satisfying peak loads, ensuring frequency regulation and providing emergency reserves;
- Water body for fisheries, recreation and inland navigation;
- Loss of land (inundation, waterlogging, shoreline erosion)

- Land reclamation and increase of arable land areas through irrigation, flood control, inter-regional water transfer;
- Changes in the environment and economy of river valleys, lakes deltas, estuaries, inland seas, and sea coasts.

With increased land value and intensification of the economic development of river valleys, and the influence of other socio-economic factors, the possibility of constructing large or very large reservoirs is becoming either limited or impossible in the greater part of the world. Small and medium-sized man-made lakes will be constructed for water supply, recreation, irrigation, flood control and other types of reservoir use which are now acquiring increasing importance.

By generalizing the large amount of experience now available concerning reservoir construction and operation, both in the USSR and elsewhere, it is possible to formulate some general principles regarding reservoir planning and justification of their economic feasibility.

- (a) A pluridisciplinary detailed study of the economic significance and efficiency of every reservoir must be undertaken prior to the design study. All positive and negative future effects of the reservoir on nature and the national economy, including during the first years of operation, must be considered. Where applicable, calculations should take into account the integrated use of reservoirs along the whole river course and their impact on neighbouring lakes and seas and suitable measures, from the viewpoint of the national economy, should be implemented.
- (b) It is necessary to develop and implement complex measures to prepare the reservoir bed and reconstruct the economy of the zone of influence of the reservoir. Project variants should be systematically studied and developed within the framework of regional planning schemes. Economic, social and ecological factors should be assessed, special attention being paid to preservation of the ecological balance and the quality of water. The inundation of valuable lands should be reduced to a minimum.
- (c) The future trends of natural and anthropogenic factors should be evaluated: hydraulic structures in the river basin, inter-regional water transfers, etc. Prerequisites for the construction of reservoirs, their parameters, preparation and operation regime should be considered as interconnected and interdependent links of one chain.
- (d) Reservoir construction should only go ahead if the sum of its effects on the group of branches of the economy in the interests of which the reservoir is to be constructed, compensates the negative effects on other branches of the national economy. The final decision can be taken only after completion of an in-depth analysis of all other non-economic factors: social, ecological, aesthetic, etc.

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PAPER 4

DANUBE BARRAGE FOR AN IMPROVED ENVIRONMENT

Laszlo S. Nagy
Hungary

The Danube and its surroundings are regarded with equal pride by eight countries in the knowledge that it has been the home of their peoples for centuries. The river - creator of several capitals and cities on its banks - has become a symbol in the eyes of the peoples united by its presence. Its name was sung in folk-songs, the history of the valley has stimulated writers and its scenery attracted the attention of painters visiting the region. The murmur and colour of its ripples has inspired composers.

71 million people live within the catchment of the Danube or 12 percent of the total population of Europe. If the magnitude of national incomes is considered as decisive, it is the first river in the world. In the absence of this water system - covering over 817 000 km² - this enormous conglomerate could not have come into being. Its water is an essential basic element - in a biological sense - for the population, flora and fauna. The river is an artery that carried the life-giving water, indispensable to the continuously developing economies and at the same time the recipient of wastewaters, the by-products of gigantic economic complexes. The capacity for self-purification of the river - thought earlier to be unlimited - is today still sufficient to digest the bulk of these wastes but the limits of natural self-purification are already looming before us.

The living character of the Danube can be preserved, its environment can be protected and further developed fruitfully only if the nations concerned are willing to exert considerable efforts in the direction of an integrated international co-operation following the concepts formulated in Helsinki.

The Danube is the highway of nations, one of the main transportation routes of Europe. The waterway - about 2 500 km long - offers in general a safe and cheap navigation route for the riparian countries and, after the expected completion of the Danube-Main-Rhine Waterway, it will be the main eastern branch of a new, united navigation system. It will be the realization of a plan that is over one thousand years old since it was Charlemagne who initiated the construction of the Fossa Carolina - a canal interconnecting the two water systems - as early as 792. The new canal will serve directly or indirectly the interests of 240 million people by assuring a connection between the water systems of the Danube and the Rhine. Three inhabitants of Europe out of four will benefit by it.

The connection between the Danube and the Rhine may promote a closer economic tie between the western and eastern regions of Europe, between countries of different social order. It is a universal constant that the economic development of areas along waterways is 40 - 50 percent higher than average in the countries concerned. Navigation not only

promotes transportation and reduces costs but also offers new opportunities for economic growth, the development of the productive forces, and the rational reshaping of the economic structure.

Navigation is the form of transportation that imposes the least harm to the environment. Its energy requirement is 30 to 50 percent less than that of other forms of transportation. This leads not only to savings in energy but also to a reduced air pollution resulting from the consumption of petroleum fuels. The investment per unit mass of freight transported by ships is 60 to 70 percent lower than in the case of road or rail transportation. Moreover, ship-building is less harmful to the environment than the manufacturing of road vehicles or railway freight-cars. Intensive navigation should positively affect the efficiency of industry and agriculture in the Danubian region by easing the traffic on road and rail networks and by facilitating the delivery of mass-products such as cement, cereals, etc. If in the future navigation routes are connected to the other transportation systems the land set aside for the development of roads and railways can be returned to the productive sphere. According to present plans for the multipurpose use of the Danube, 49 barrages are required of which 29 are already in existence and 3 are under construction. Downstream of the confluence with the Danube-Main Canal - on the Danube reach which will be a part of the all-European Waterway system - 7 barrages are in operation in the Federal Republic of Germany, where two more are required and a further 8 in Austria.

At the Iron Gate - which was the principal obstacle to navigation - a joint Yugoslav-Rumanian Barrage has been operating since 1972. "Iron Gate II", another barrage 85 km downstream will be finished in 1986. The foundation-stone of the barrage at Turnu Magurale was laid in 1978 on the Rumanian-Bulgarian reach.

Due to its geographically central situation and hydrographical characteristics Hungary can play a substantial role in inland navigation between the western and eastern regions of the European continent. In Hungary, the Danube is navigable over a distance of 417 km although its total length, together with the communicating waterways, is 1 640 km.

The provision of modern shipping infrastructures and their continuous maintenance is one of the main tasks to be undertaken by the authorities responsible for the water management of the Danube. The final goal is, however, much more complex and includes the maximum possible utilization of the river's potential. The harmonious achievement of this objective is very important for water management in Hungary on account of the basin-like geographical situation of the country.

96 percent of Hungary's surface waters arrive from neighbouring countries burdened with the increasing demand of civilized societies subject to considerable economic growth. Waters running off the high mountains of the countries upstream are accumulated in the Hungarian plains often causing serious floods. Due to topographical and climatic conditions a flood is usually followed by a severe drought whose negative effects can be eased only by the use of water stored in reservoirs.

The dynamic growth of the national economy calls for more and more water. At the same time the prevention of floods and the protection of the quality of water can be attained only by a concerted, elaborate quantitative and qualitative control of the hydrological regime.

Recently the importance of hydropower has grown considerably due to the energy crisis as well as on account of some novel aspects of environmental protection. Hydropower is

inexhaustible since it is regenerated continuously. Operation and labour costs are low and no harmful side effects of any kind are produced. The energy potential of the Danube is enormous: the economically exploitable potential is sufficient to supply more than 20 industrially developed cities of the size of Budapest.

The multipurpose development of the Danube is reflected in the plans of the Nagymaros-Gabcikovo Water Barrage System to be undertaken jointly with Czechoslovakia.

Coordinated Hungarian-Czechoslovak investigations were started in 1951/52. Since then the original technical-economic proposals have undergone a number of development stages. The users' demands have become more and more complex, and technical solutions and management practices have evolved.

In order to have a thorough understanding of the natural conditions which determine the barrage system as a whole, relevant data had to be analyzed concerning the following disciplines: topography, geology, hydrogeology, hydrology (including river stage, discharge) navigation conditions, ice phenomena, sediment transport, soil mechanics, meteorology, seismicity, etc. The research work on hydraulics; seepage, civil engineering structures, hydromechanics and the model investigations depended on the basic investigations, executed by specialized research institutes and by university and industrial laboratories.

The starting point of multipurpose project planning is an examination of the main sectors of the economy which are to benefit from the project: regional and urban development, energy, navigation, agriculture, environmental protection, water management, flood protection, land drainage, surface and groundwater quality, regional water supply, etc. All must be analyzed individually and then coordinated and optimized.

In order to achieve this task a special coordinating system having international status was set up on the recommendations of the Danube Committee, as it must be recalled that the river forms here the state boundary between Hungary and Czechoslovakia. A determinant factor is that the new barrages must be integrated with the nearest Austrian barrage upstream and the planned barrages at Adony, Fajsz and the first Yugoslavian barrage downstream. The socialist countries of the Danube basin have agreed upon the main aspects of a policy of coordination for the utilization of the Danube between Pozsony and the Black Sea (CMEA - Danube Complex).

The plans were scrutinized according to the procedures for approval and state administration laid down to meet the current investment procedures.

Special efforts are being made to study the consequences of the project, its environmental impacts and the elimination of dangers. This has involved about 50 studies concerned with environmental protection, agriculture and urban development. The integration in the landscape of the Nagymaros Barrage has been investigated by a team of architects. The jury consisted of a number of professionals, representatives of the Hungarian Academy of Sciences and of the Society of Hungarian Architects. The problems of biological equilibrium were studied by several university institutes. An important part of the preparatory work consisted in the careful exploration by archeologists of the Hungarian National Museum of zones where construction work will upset a landscape whose balance has developed over several millenia. Although the main goal consisted in the protection of sites, a lot has been learned about the "limes", the boundary of the Roman Empire, and about the ancient civilizations in the Carpathian basin.

Following this preparatory stage a Common Agreed Plan was formulated for the documentation of the technical solution, with the participation of several hundred institutions and organizations and thousands of experts and international specialists. An Interstate Agreement was drawn up and approved by the Prime Ministers of the two countries to construct and commonly operate the Gabčíkovo-Nagymaros River Barrage System.

The main technical features of the project are as follows: A weir will raise the level of the Danube at Dunakiliti creating the Dunakiliti-Hrusov Reservoir. From this reservoir a diversion canal will carry the flow of the Danube to the Gabčíkovo Barrage (Bos, Hungary). The water will return to the original river bed at Palkovicovo (Szap, Hungary). The downstream element of the system is the River Barrage of Nagymaros, operated in conjunction with the aforementioned structures. The Gabčíkovo Barrage, the diversion canal and the greater part of the Dunakiliti reservoir will be situated in Czechoslovakia while the Dunakiliti weir, a smaller part of the reservoir and the Nagymaros Barrage are in Hungary.

The national borderline will remain unchanged. The area occupied by the structures of the barrage system will cover 10 000 ha in Czechoslovakia and 4 000 ha in Hungary. At the same time, several thousand hectares of temporarily wet agricultural land will be placed under permanent cultivation.

The Dunakiliti Reservoir will occupy the flood plains between Dunakiliti and Pozsony, in other words, the area within the existing flood protection levees. Its function is to collect and store the waters for further use. Twice a day sufficient amounts of water will be available for energy production during the peak periods. Its total capacity will be 200 Mm³, with a useful capacity of 60 Mm³.

The Dunakiliti weir regulates the water level in the reservoir and releases an appropriate discharge into the bed of the old Danube. An auxiliary navigation lock will also be constructed at the weir, if needed.

The 25 km long diversion canal is subdivided into two parts. The 17 km upstream stretch leads to the Gabčíkovo Barrage between dykes. The 8 km downstream stretch ends at the confluence with the old Danube at Palkovicovo (Szap). The main navigation route will follow the diversion canal.

Eight turbines will be installed at the Gabčíkovo power plant with a total capacity of 720 MW. A lock will also be constructed here. The power plant will be operated mainly to satisfy the morning and evening peaks.

The river bed between Dunakiliti and Palkovicovo (Szap) will have a continuous but reduced flow: it will take part in flood attenuation and in ice discharging. The continuous flow of freshwater past the weir, the dammed tributary system along the stretch which allows seepage from the tributaries to the old channel and the floods appearing several times during a year, will all contribute to maintain the present natural and environmental conditions. The extremely variable groundwater regime prevailing today will be smoothed out in the new situation.

The Nagymaros Barrage will compensate the streamflow released by the peak-operated power plant at Gabčíkovo and its backwater extending to the Gabčíkovo Barrage will ensure the draught required for navigation. The Nagymaros power plant will operate as a base

plant with six turbines of 160 MW total capacity. The weir will be equipped with seven gates, each 24 m wide. Navigation will be provided with a lock.

Upstream of the barrage a number of structures will be constructed to maintain or even improve the present state of environmental conditions. Downstream of the barrage the river bed will be improved down to the southern end of the Island of Szentendre.

With the construction of the barrages system:

- the natural hydraulic energy of the river will be utilized from Pozsony to Nagymaros with an annual average energy output of 3.6 TWh from the two power plants. 40 percent of this amount will be delivered during peak-demand, 5 hours daily. Hungary's share will be 50 percent of the total installed capacity and of the energy produced (440 MW and 1.8 TWh per annum, the equivalent of 650 000 to 700 000 t of heating fuel);
- a navigation route will be developed which satisfies the recommendations of the Danube Committee even in the long-term. The useful time base for navigation will be increased by 40 percent, the load capacity of barges and ships by 20 percent whereas the energy demand of navigation will be cut by half;
- the dykes of the reservoir and the levees constructed for flood control and the dual routing of floods - in the old river bed and in the diversion canal - will ensure a much higher safety for the national assets in the protected area;
- the infrastructure constructed within the framework of this investment will serve directly the development of the region. These include the modernization of the road network in the Danube Bend, a road bridge between Nagymaros and Visegrad, the supply of the region of Nagymaros with drinking water, the regional wastewater treatment for Nagymaros, Visegrad and Domos, a restaurant to be built in Nagymaros, a workers' hotel to be used later as a tourist hotel, the enlargement of the sewerage network of the town of Esztrgom, the small-size regional waterworks to be constructed at the north-western edge of Szigetkoz, the road network to be constructed in the flood-plains of the old river bed near Szigetkoz for channel maintenance works but also for touristic purposes, the protection of an as yet unprotected area of 1 000 ha against floods, the solution of land-drainage problems around Visegrad, Gonyu and around the confluence of the Ipoly river, etc. The construction of stabilized shorelines, the landfills improving the environmental conditions and serving the urban development, the possibilities offered by the increased water surfaces, the inclusion of the tributaries of Szigetkoz into permanent water motion, the separation of the water supply of the Mosoni Danube from the hydrological regime of the Danube, the regulation of groundwater and the development of land drainage in Szigetkoz, etc. will all affect indirectly the everyday life of this region in a favourable manner.

To assure flood control and satisfactory navigation and to provide good quality water certain steps will have to be undertaken. These will be most efficient if they are concerted and subjected to certain guiding principles and will depend upon the completion of certain other measures. Besides meeting the basic goals, the opportunities offered by the river can also be utilized, and the extent of risk situations reduced. These multiple activities will entail, at the same time, a conscious development of the environment itself.

Unfortunately, the "Blue Danube" has not been so blue for a long time despite the fact that the quality of its water has become slightly better. In Vienna and Bratislava new

wastewater treatment plans have been completed and in Slovakia considerable efforts are made to improve the water quality of the Vah River. These are indications of an awareness in the countries of the Danubian basin that the improvement of water quality in the respective river reaches is also in the interest of their own environment.

Simultaneously with a reduction of water consumption, the quantity of wastewaters will also be reduced. If up-to-date, environmentally-sound technologies were introduced then not only a reduction in the quantity of wastewaters could be achieved but a large quantity of products now wasted could be recovered. If plant protection is practised and fertilizers are used on a scientific basis combined with due technological discipline then not only the discharge of nutrients and toxic substances into the waters could be reduced or eliminated but considerable savings in the cost of these expensive chemicals could also be achieved. The assumption that the result of such a complex approach will be to reduce the pollution of the Danube along its domestic stretch, is quite justified.

The realization of the river barrage system will lead to a fast "processing" of the pollution of the Danube. The turbines - acting as large propellers - will stir the water intensively. In the course of rapid turbulent flow the water is able to absorb a considerable amount of oxygen and in this way its capacity of self-purification is raised. In the present pattern, an important part as regards oxygenation is played by the fact that during the late summer period of low-waters - critical from the aspect of water quality - the system of river branches in Szigetkoz is not replenished by freshwater and becomes swampy in several places. Due to the realization of the barrage system this replenishment will be resolved and continuously replenished water surfaces will be formed. Consequently, in accordance with international experience gained in fluvial systems of this type, the overall water quality of the Danube will improve in this particular river reach.

It is widely known that management patterns which disregard environmental aspects have spread to such an extent all over the world that, in many places, their influence can attain waters lying deep below the ground.

The completion of the barrage system will result in a further replenishment of water in the gravel layer underlying Szigetkoz and through the formation of a stabilized, permanent groundwater level it will increase the yield of wells along the Danube, improving thereby the water supply of Budapest.

In the dammed river stretches, there will be no pollution due to sedimentation. The total annual volume of suspended load carried by the water through the Dunakiliti weir will be 2 Mm³ on average. Only a small portion will settle due to the drop of the velocity in the reservoir, the area of which is equal to about 60 km². This represents a layer of siltation whose order of magnitude can be expressed in millimetres on an annual basis. Due to the joint side effect of the grain-size distribution of the soil and the hydrostatic pressure, such conditions will develop where the intrusion of fine silts into the soil-gravel layer may amount to a few centimetres only. Within a reasonable time, the surface of this gravel layer will become impervious. The situation is different in the reach between Dunakiliti and Nagymaros, where, due to higher flow velocities, the possibility of sealing is even less. As to the vicinity of the capital, the water flowing downstream from the river barrage at Nagymaros, being poor in suspended load, will exert an undoubted favourable impact on water quality.

The environment must be protected against floods too. The implementation of the river barrage system will increase the security of the area.

The operation of the weirs in the barrage system will be harmonized by well-designed and strict operation rules. The basis of this programme is the reliable forecasting of river stage.

By an hourly check the water levels within the barrage system can be continuously controlled. The storage capacity can be emptied several days before the arrival of floods. During floods, the hydropower production will be shut down, the gates will be raised, and the increased discharges will be conveyed safely by the Old Danube.

In this mode of operation the flow regime of the Danube will be the same as it is now but the diversion canal - acting as a flood relief canal - will divide the floods and multiply the protected areas of Szigetkoz. Downstream of Szigetkoz the levees to be constructed as a part of the investment at Nagymaros will create greater security. In the period of average or low waters with simultaneous damming, an accidental failure of the weirs will involve no flood risk at all. The flood wave resulting from an instantaneous and complete failure of the Nagymaros weir will be attenuated to such an extent that the water level will not reach the lower quays at Budapest. Moreover, the probability of such an accident is extremely low because the country is a relatively quiet area from the point of view of seismicity and damage due to earthquakes was taken into account by suitable dimensioning of structures.

The harmonized operation of the barrage system will also allow the flexible and optimal matching of the momentary needs of both power production and water supply.

These important topics illustrate that during the course of planning pursued during decades by Hungarian scientific institutes, a multitude of problems of this character have been considered and discussed. The overall conclusion is that on the basis of present knowledge, the Gabčíkovo-Nagymaros Barrage System is well founded as regards practical protection and rational development of the environment.

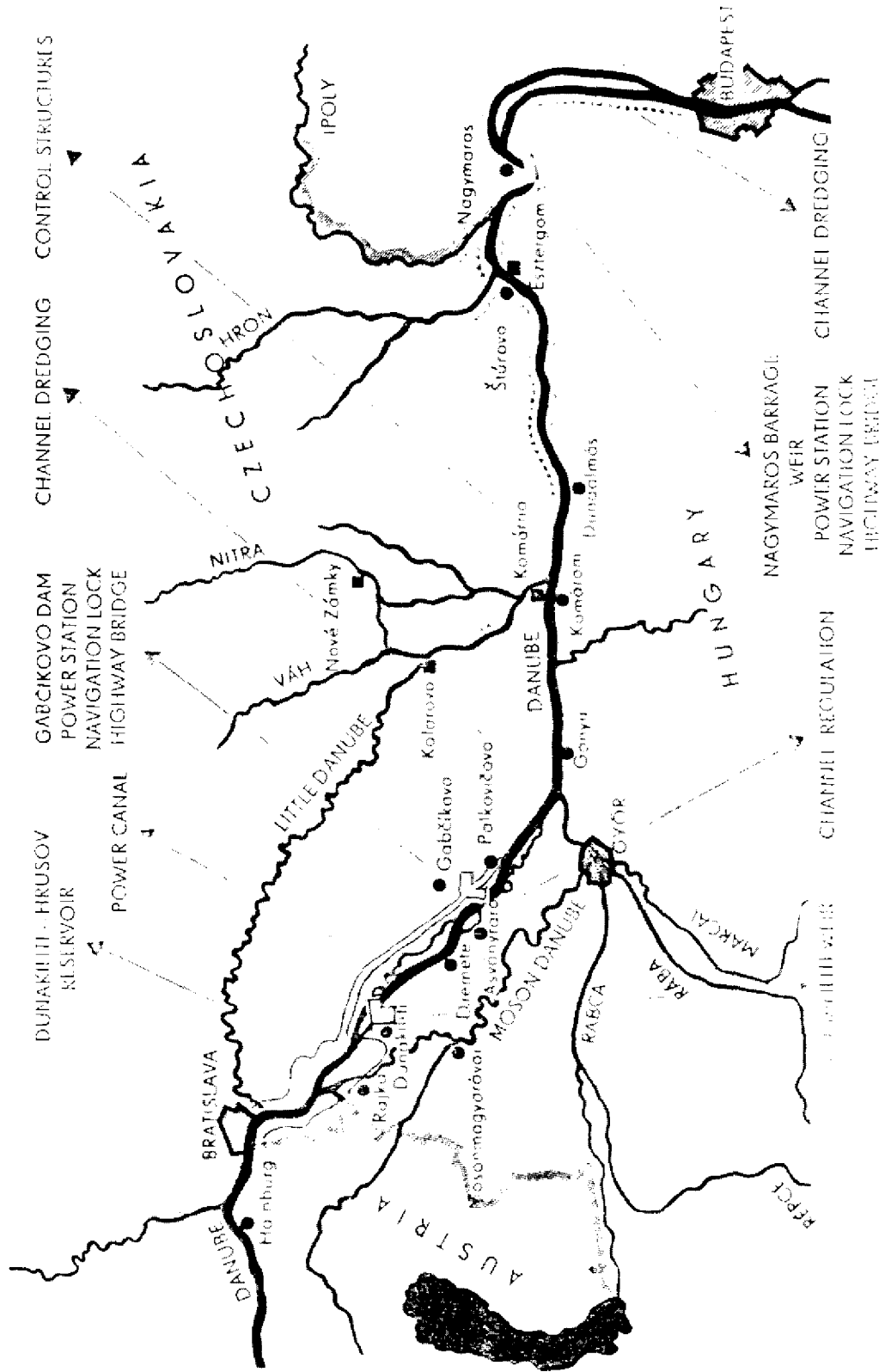
Nowhere in the world has any study been prepared where the technical, economical, environmental implications and the associated risks of such a great project have been analyzed as a single system, due concern being given to all inter-relations. The impact study prepared for the Gabčíkovo-Nagymaros Barrage System is considered as one of the first in the water sector of Europe in which a full analysis of the impact mechanism of a ramified problem has been investigated, including the conditions of equilibrium and regulation.

It is sometimes a rather difficult task to find an explanation of the most evident phenomena. However, the economy of hydropower plants is best proven not only by existing and recently constructed hydropower stations in neighbouring countries but also by the sometimes not easily quantifiable data obtained by the comparison of different technologies of energy production.

When comparing the environmental impact of different types of power plants, hydropower plants are found to have the most favourable economic performance.

Along the long route followed by oil and coal between the site of production and the site of combustion there are numerous occasions of harming the environment. The most dangerous, however, is the conversion of energy, in the form of noise and of thermal atmospheric and water pollution. The emission of sulphur dioxide produces acid rains. Expensive methods are required for the protection of the living aquatic environment against the by-products of water softening plants operated in conjunction with the thermal power plants.

Map of the Gabčíkovo—Nagymaros Barrage Project



In case of failure, black oil may reach the rivers. In general, provisions for the safety and health of the people working at places where such harmful influences can occur, use up considerable national resources. The costs of purifying water and air in advanced technological processes cannot be compensated by fines paid by the polluting plants. The electric energy generated by the thermal plants is consumed partly by their own equipment in performing dust separation, desulphurization and acid neutralization, reducing thereby the amount of energy to be transferred to the grid. Due to the more and more strict regulations aimed at protecting the environment, the internal energy consumption of thermal plants is continuously increasing.

At the present level of economy the production of energy with fossil fuels is considered as self-reducing, since its harmful impact on the environment has to be countered by using part of the energy output. A hydropower station does not produce any waste so that hydropower development is environmentally the soundest way of producing energy.

PAPER 5

THE IMPACT OF FLOOD MITIGATION PROJECTS IN THE KLANG RIVER BASIN OF MALAYSIA

C.H. Sea⁵

1. Introduction

1.1 Flood Problems

The Klang River Basin drains a catchment area of about 1 200 km² (Figure 1). Kuala Lumpur, the capital and commercial centre of Malaysia, with a population of about one million (in 1980), is situated in the flood plain of the river. From the earliest days, the city of Kuala Lumpur has been subjected to flooding. Between 1949 and 1979, seven flood events of the Klang River were recorded at Market Street where the maximum channel capacity is 170 m³s⁻¹. These events, in descending magnitude, had the following streamflow values:

Date	Discharge (m ³ s ⁻¹)
January 5, 1971	569
November 17, 1972	289
April 28, 1952	213
November 21, 1951	196
December 17, 1959	189
November 25, 1973	181
October 26, 1957	175

The 1971 flood resulted in an estimated loss of US\$ 13 million.

Flooding is usually caused both by monsoon depression-type storms which are widespread and of long duration, and by convective storms which are localised, intense and of short duration. The potential for flooding is not confined to the monsoon season but can occur with very little advance warning at any time of the year.

⁵ *Drainage and Irrigation Department, Malaysia.*

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The increased rate of urbanisation has brought about higher flood peaks and extended the area of damageable properties.

1.2 Water Supply Needs

The city of Kuala Lumpur has, on at least two occasions, suffered from a shortage of municipal and industrial water. The earlier shortage occurred during the 1950's and led to the construction of Klang Gates Dam which was completed in 1959. The second shortage occurred during the middle 1970's and resulted from the combined affects of increasing population and a two-year drought. The daily per capita rate of water use in 1975, including industrial needs, averaged 326 l. It is expected to increase to 445 l by the year 2000.

In 1975 the Government of Malaysia with assistance from the USA prepared and implemented a comprehensive flood mitigation scheme, known as the Kuala Lumpur Flood Mitigation Project.

2. The Kuala Lumpur Flood Mitigation Project

2.1 General

The main features of the project include three dams located on the Klang, Gombak and Batu Rivers and flood channel works on each of these streams (Figure 2). The dams will provide flood control, retention of sediment, and provide municipal and industrial water for use in the project area.

2.2 Description of Major Works

2.2.1 Channel Improvement

The river channel improvement programme involves widening, deepening and straightening of 47.2 km of river channel above the Puchong Bridge and removal of the Puchong Drop structure to assist with the evacuation of flood flows. In the rural areas above and below Kuala Lumpur the improved sections of the rivers will remain unlined. Within the city where space is restricted, sections will be lined and will be deeper than the unlined sections because of higher velocities in these reaches. When completed, the channel capacity in the critical sections of the river between the confluence of the Klang and Gombak Rivers and the Sulaiman Bridge will have been increased to $736 \text{ m}^3\text{s}^{-1}$.

2.2.2 Klang Gates Dam Modification

The Klang Gates Dam and Reservoir provides a normal municipal and industrial water yield of 1 570 to 1 840 ls^{-1} depending on day-to-day operation and incidental flood control. The height of the gravity arch concrete dam has been raised by 3m to an elevation of 97.8m.

With the enlargement of the reservoir, the new active capacity of 28.8 Mm^3 will represent an increase of more than 76 percent over the previous active capacity of 16.3 Mm^3 . Whereas the existing reservoir has only incidental flood control capability, the enlarged reservoir with 6.2 Mm^3 of flood control capacity could reduce the 100-year flood peak at the Market Street Bridge by $138.8 \text{ m}^3\text{s}^{-1}$.

The entire area to be inundated by the enlarged reservoir is in a forest reserve and no houses or buildings need to be relocated.

2.2.3 Batu Dam and Reservoir

Batu Dam is to be constructed on the Batu River downstream of the confluence with the Tua River, where it will provide maximum regulation. A dam at this site controls surface runoff from 50.2 km². The dam will be an embankment dam impounding water to an elevation of 103.8 m, creating a reservoir with a capacity of 36.6 Mm³.

The reservoir will inundate 235.6 ha of land. However, additional lands needed for roads and other project functions and services bring the total area required to 311.6 ha of which 274.8 ha will have to be replaced.

2.2.4 Gombak Dam and Reservoir

Appraisal studies made indicate that Gombak Dam will be a multiple-arch concrete structure about 25 m in height above stream-bed. At maximum pool elevation of 82.3 m, the reservoir will inundate an area of about 380.6 ha. Additional lands required for roads and other services are expected to bring the total land needed to about 411 ha.

The Gombak Reservoir will inundate an area inhabited by about 3 000 people in 761 houses, according to a 1973 survey. It was reported in 1979 that 1 110 families representing 4 523 people resided in 876 houses in Gombak North Village and Chinchin Village in the reservoir area. The residents are served by a mosque and a religious school. Suitable replacement lands and other assistance would have to be provided for relocation of people and homes.

3. Hydrological, Social and Environmental Impacts

During the planning stage of the project, extensive assessments were made concerning the hydrological, social and environmental impacts the project would have in the areas affected (Univ. Malaya, 1980, 1981).

3.1 Hydrological Impact

River flows in the basin are extremely flashy, being influenced by intense precipitation from convective-type localised rains of short duration or from tropical depression-type storms of long duration which pass over the area.

Removal of forest cover and urban development would be expected to increase runoff to the rivers. It was estimated that the virgin forest in Malaysia retains 36 to 46 percent of the precipitation, whereas logged areas retain 20 percent and rubber plantations and urbanized areas from 14 to nearly zero percent. A study of the Ulu Gombak Forest Reserve (Kenworthy, 1969) revealed that total runoff was increased by 33 percent when trees were replaced by grass or crops.

In order to investigate further the hydrological impacts of the Flood Mitigation Scheme, a Flood Risk Analysis and Mapping project was carried out. This project was initiated by the Typhoon Committee under the Economic and Social Commission for Asia and the Pacific (ESCAP) in 1985. The analysis relates changes in the catchment such as deforestation, urbanization, dam construction and channelisation with flood flows in the

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rivers. The project, which is still in progress, will analyse river flows under the following conditions:

- (a) Present catchment with existing channel.
- (b) Future catchment with existing channel.
- (c) Future catchment with future channel.

Preliminary results in the Klang River indicate that with the same rainfall intensity, the discharge would be almost twice as great for the future catchment compared to the present.

They also show that with the same rainfall intensity, the discharge of the future channel would be slightly higher than that of the present channel. This is consistent with the fact that the improved channels would carry a higher flow downstream. However, the water levels in the improved channel would be lower, and therefore less area would be flooded.

3.2 Social Impact

The present community is closely-knit, drawing its identity and cohesion from Malay ethnic sentiments, traditional norms, and strong kinship ties and constraints and in their case the adverse effects of the proposed dam would include loss of land, loss of income and loss of livelihood, as well as family dislocation.

It has therefore been recommended that the replacement land should be located within commuting distance of the present residence of the affected groups. In addition a suitable Community Improvement Programme could be integrated in the overall package deal, involving land replacement and other related compensation dues. This programme would include the following notions:

- (a) a concept of community development in a context of urbanization,
- (b) cultural parameters in community development such as use of space, dominant value-complex, neighbourhood and essential social-cultural amenities, and group solidarity.

3.3 Environmental impact

3.3.1 Aesthetics

The scenery of the Klang Gates Reservoir is attractive. Nearly vertical bare rock outcrops contrast with jungle-clad slopes and the water. Clearing for project facilities in the vicinity of the dam has enabled species such as bamboo and ferns which require light to invade the jungle edge and increase the jungle's vegetative diversity. Batu and Gombak Reservoirs probably would resemble Klang Gates in most respects.

3.3.2 Water-borne Diseases

Construction of dams at Batu and Gombak sites is not likely to cause an increase of water-borne diseases. The parasite, *Shistosoma japonica*, which causes schistosomiasis in other Asian countries has not been reported in Malaysia. Waters of the proposed reservoirs

would not provide the sluggish, vegetative-choked conditions required by the parasite's host snails (Chandler, 1958).

3.3.3 Water Quality

At present, rivers in the project area have been polluted to varying degrees. For instance, samples of water taken from above and below the city showed that BOD levels increased from 1.0 to 300 mg l⁻¹ while DO decreased from 99 percent saturation to near zero. There is also a high concentration of suspended solids due to natural soil erosion and erosion resulting from tin mining, housing and agricultural activities.

The Klang, Batu and Gombak Reservoirs are incapable of storing sufficient water to provide sustained flows of sufficient magnitude to ensure that pollution would be diluted for an appreciable distance downstream.

3.3.4 Wildlife

Peninsula Malaysia, like much of the tropics, has an extremely diverse flora and fauna. Most species are widespread but few are naturally numerous in any one location. The Malayan forest contains some 2 500 different tree species, several hundred of which occur at the low elevations where the project features are located.

The inundation and occupation of some 800 ha of disturbed and forest lands by the project facilities and operational needs should have no great effect on any of the larger species of animals which occasionally visit the areas. These animals still have a considerably larger foraging range than that to be cleared for the project. The smaller terrestrial mammals will probably move into adjoining forest. The environmental assessment of the project was completed in 1977 and indicated that no endangered species were known to exist in the areas (Univ. Malaya, 1981). The diverse habitat provided by subclimax woodland primary jungle and open water at the reservoir sites should provide niches for considerably more species.

4. Conclusion

The findings contained in the reports conclude on the economic justification for implementation of the Kuala Lumpur Flood Mitigation Project.

The water supply studies indicate that the three reservoirs can yield 3 545 l s⁻¹ of water for municipal and industrial use in the city of Kuala Lumpur to augment supplies from the other sources.

The reservoirs can contain the 100-year flood at each dam and in conjunction with the improved river channels, can provide flood protection to the city for all floods up to and including the 100-year flood event. Without flood capacity in the three reservoirs, the improved channels can provide flood protection for floods up to the 55-year event.

The reservoirs can reduce the sediment load passing into the lower Klang River and probably reduce the dredging now in progress. Water releases can be made to the Batu and Gombak Rivers to maintain a live stream.

The social impact from the project, particularly as concerns settlement relocation, could be overcome by implementing the recommendations made in the reports. The environmental impacts are minimal, and would not result in serious effects.

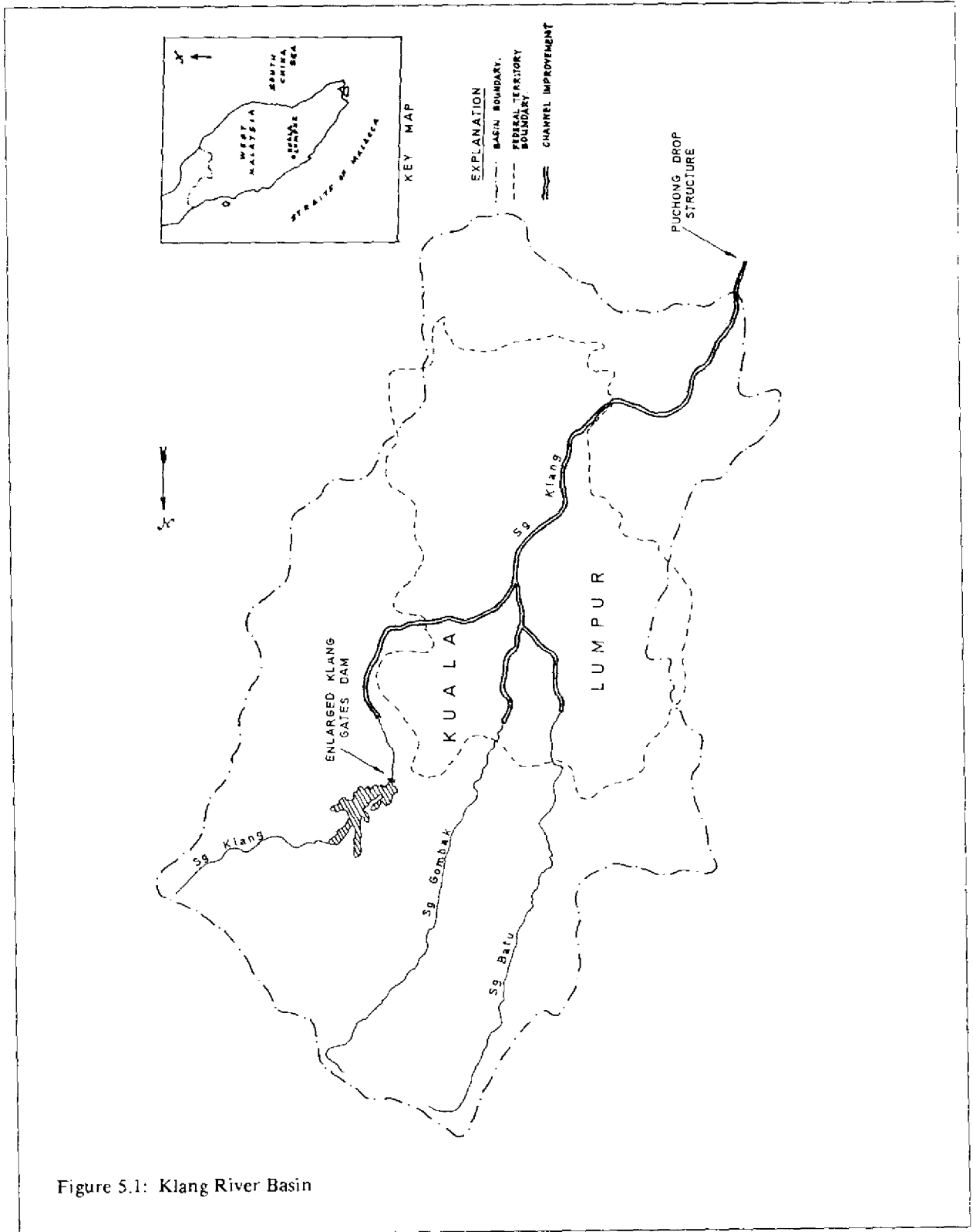


Figure 5.1: Klang River Basin

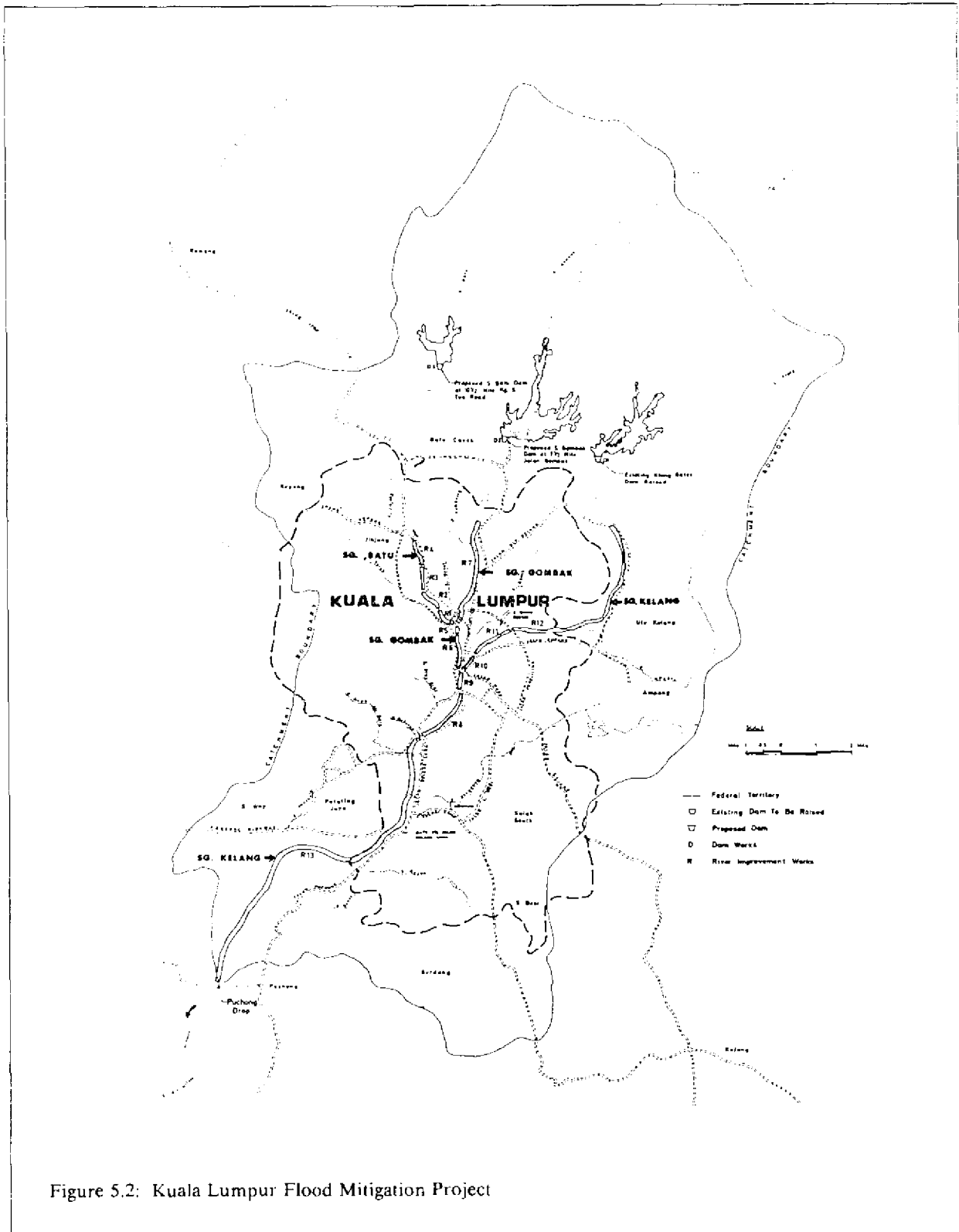


Figure 5.2: Kuala Lumpur Flood Mitigation Project

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The planning and implementation of the Kuala Lumpur Flood Mitigation Project indicate that a comprehensive study covering among others, the social and environmental aspects of a water resources engineering project should be carried out to ensure that benefits from the project outweigh any adverse and at times irreversible consequences.

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PAPER 6

EVALUATION OF THE AGRICULTURAL ENVIRONMENTAL IMPACTS OF A DANUBE BARRAGE SYSTEM IN HUNGARY

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1. Historical and Geographical Comparison - Values and Claims

Preparations for the complex utilization of the Hungarian stretch of the Danube have started. The Bos-Nagymaros river barrage system is under construction on the Danube. In the local context this project, which emanates from a Czechoslovakian-Hungarian "Joint Conventional Plan" can be considered to be very large. Its expected natural and social impacts and its importance make it comparable to the flood control and drainage works undertaken in the last century and whose impacts on Hungarian agriculture are still felt today.

These projects resulted in long-lasting and large-scale improvements of the agricultural production conditions of the Tisza Valley primarily. They have increased the agro-ecological potential and agricultural productive capacity of an area of more than 2 Mha.

Historical and geographical arguments associated with water projects cannot in themselves be invoked for or against projects or methods and applied technologies. However, the experience gained elsewhere in other times is a valuable store of knowledge from which to draw when devising action alternatives, allowance being made for the new set of economic conditions, objectives and available means.

River barrage systems comprise a number of subsystems namely river structures and the natural and artificial environment. These subsystems may differ considerably depending on geographic location on the same river even if constructed at the same time. The natural and artificial environment offer the greatest variability. Every barrage complex has specific features and peculiarities.

This concept will be retained to analyse the historical and geographical experience to be gained from the agricultural and environmental impacts of the Bos-Nagymaros barrage complex.

The summary results of this environment-management study were formulated in 1982 by an *ad hoc* committee convened by the President of the Hungarian Academy of Sciences. The report states that there are no agricultural or environmental reasons for discouraging the implementation of the Bos-Nagymaros river barrage system. Such a reason could have been an economically unavoidable ecological collapse in one or more of the highly valuable

sectors of the affected area. The water balance might be temporarily or permanently modified locally or in larger contiguous areas. From the viewpoint of nature or society these changes can be favourable or unfavourable. The committee made few references to the possibility of increasing the agricultural potential or exploiting the environmental advantages. During the last three years often lively multilateral discussions have taken place in an attempt to clarify the nature of the agricultural and environmental impacts still unexplored and to quantify them.

Since all decisions involve the determination, assessment, comparison and ranking of relative values and interests, the aim of impact studies is to explore as far as possible, the natural and social scales of values and interests and, where possible, to quantify them. The part of the report which deals comprehensively with the quantification of agricultural and environmental values and interests meets the aforementioned requirements of an impact study, despite some "gaps" and certain simplifications.

2. Agro-environmental impacts and their evaluation

Some initial questions can be formulated:

After completion of a river barrage, what possible changes in water balance may directly affect the agricultural environment? What are the characteristics of these changes and what are the resulting interactions?

The impacts to be considered as regards an agricultural environment are those which have direct practical consequences.

The inundation or drainage of some agricultural areas and the rise or drop of groundwater levels can be expected to result from the presence of river barrages. These effects will modify the size and/or the productivity of agricultural lands. The area to be affected by the Bos-Nagymaros barrage system can be divided into three major regions (Figure 1). The land-use distribution is shown in Table 1.

In addition, especially in the initial stages of construction, a total of some 3 000 ha will be lost to production, of which 1 000 ha are ploughland, whilst grassland and woods will each lose 500 ha.

Due to various landfills a new area of some 120 ha will be available for cultivation, a considerable portion of which lies within built-up areas, with a corresponding increase in value.

In the regions of Komárom, Esztergom and Pilismarot and in the Ipoly River Valley about 2 000 ha are unfit for intensive agricultural production due to frequent flooding. In the future, protection works will ensure the complete safety of these lands. In Szigetkoz, an area of 30 000 to 32 000 ha will be regarded as more valuable agricultural land due to increased flood protection. From the viewpoint of agriculture the most significant change resulting from the barrage will be the drop or rise of groundwater levels.

What are the general characteristics of the predicted hydrological changes?

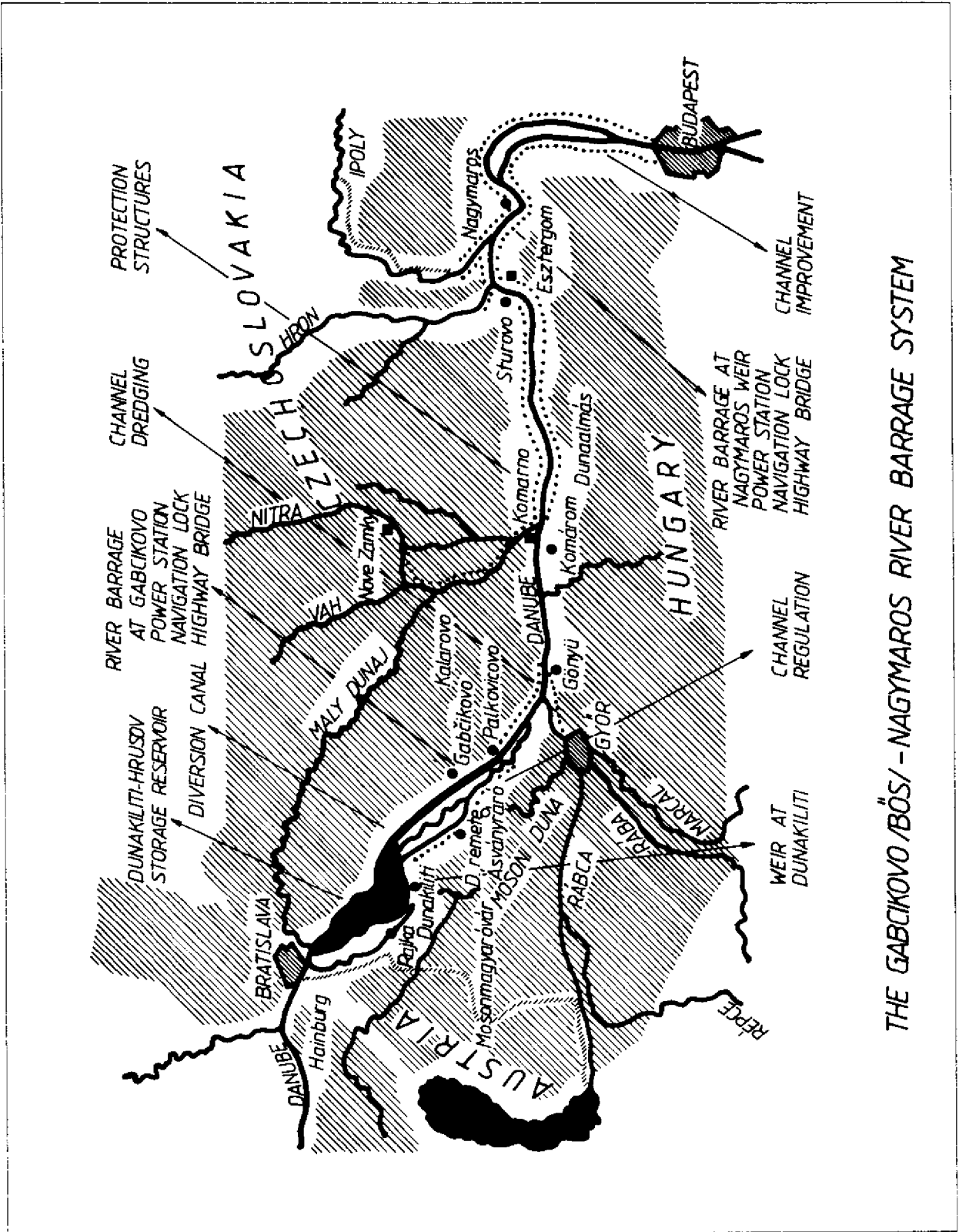
First of all should be noted their spatial and temporal variability over the area affected by the barrage. This variability can be influenced in time, especially in micro- and meso-sizes, by the discharge of the Danube, the depth, intensity and frequency of rainfall

LAND-USE	REGIONS					
	Szigetkoz		Gonyü-Nyergesujfalu		Nyergesujfalu-Nagymaros	
	ha	%	ha	%	ha	%
Ploughland	19 000	63	18 122	66.1	3 033	44.5
Grassland	3 400	11	2 499	9.1	391	5.8
Vineyards and Orchards	280	1	1 222	4.5	27	0.4
Market Gardens	280	1	2 100	7.7	2 478	36.3
Forest	7 300	24	3 454	12.6	882	13.0
Total Agricultural Land-Use	30 360	100 92.1*	27 397	100 85.9*	6 811	100 78.2*
Industry and built up areas	2 701		5 259		1 977	

* Percentage of the total affected area.

and, finally, the rate of evaporation and, above all, evapotranspiration. An important spatial element of variability is the thickness and the physical-chemical properties of the upper soil layer, the geomorphology and the conditions of surface and underground slopes, etc.

What is characteristic of the interactions within a habitat that can develop as a direct consequence of changes of groundwater levels?



THE GABCIKOVO /BOS/ -NAGYMAROS RIVER BARRAGE SYSTEM

2.1 The nature of interactions

The interactions discussed here are those, variable in time and space, which exist among the hydrological, soil and climatic conditions, the individual hydraulic structures and the destination and technology of land-use. Furthermore, the interactions between natural and social factors, vary throughout the affected area, including in time. Not all of the individual elements nor the direction of their movement, or rate of change of quality are accurately known, even in the present situation, much less in the future.

One of the particularities of making forecasts of the interactions which may arise from a barrage is that the technical actions are mostly quantitative but their environmental or ecological impact is mostly qualitative in nature.

2.2 Agro-environmental impact assessment: Methodology and main findings

The agricultural impact study of the essential changes of hydrological conditions and water balance was undertaken jointly by research workers of the University of Agricultural Sciences at Keszthely and others. Based partly on data obtained from this source a new method was developed for the quantification of impacts in the Department for Water Management and Amelioration of the University of Agricultural Sciences at Godollo. The essence of this method of assessment and calculation is the definition of so-called areal eco-types, partial areas relatively homogeneous in terms of ecology, (soils, hydrology, geomorphology, climate) suitable for defining the average situation prior to construction. For these eco-types the wheat and maize yields attained 50 percent of the time were calculated. In this way the present practical average agro-ecological potential was quantified for all eco-types, in terms of yields.

Based on these parameters, the different eco-types and their areal extent were determined for the hydrological conditions and water balance situations expected to occur after completion of the barrage system and, the agro-ecological potential of these eco-types determined in terms of wheat and maize yields.

For Szigetkoz the agro-ecological potential is the following:

	Initial state	Subsequent state
Wheat (t ha ⁻¹)	6.0	5.97
Maize (t ha ⁻¹)	8.36	8.09

The data obtained by VIZITERV for the two other regions is similar.

What this shows is that for average hydrological and climatic conditions and accepting the predicted groundwater levels, changes of yields expressed as an overall average for the whole area are not significant.

To suit the changing environmental conditions the strategies of land-use, environmental protection and amelioration should be formulated in accordance with the possibilities, seeking the intersections of the optimum curves of ecology and economy. From the viewpoint of agro-environmental impacts the greatest danger results from lack of preparation, the lack of action programmes at village and farm level, or the failure to implement these. In such cases, although perhaps locally or temporarily only, losses may attain a maximum and benefits drop to a minimum. The examination of probable impacts on forest areas was carried out in a different way.

The expected change in the bio-mass and composition of species of *field- and woodland-wildlife* is less well known. In order to establish the initial condition, a joint programme of observation of migration extending to Czechoslovakia, is required.

The areas of *nature conservation* and the protected natural reserves of the region concerned represent ecological values other than those of the agricultural area. An advanced stage has been reached in the preparations of a district landscape protection plan extending over an area of some 8 000 ha.

The change in the *stock of fish* is indirectly linked with agro-environmental protection. In the reach upstream of Nagymaros it is probable that the hydrobiological conditions for Danubian fish will be improved. In the Szigeikoz reach, however, a considerable modification in the composition of species is expected and intensive research work is in progress.

The complex of barrages and its individual elements are certain to have an important bearing on the *landscape* of the affected area. Water and land-use for agricultural production are integral parts of a landscape. The conservation and improvement of the landscape potential calls for a concerted action on the part of all concerned with the development of the affected area.

3. How to proceed? Further tasks

Land-use can also be affected by many and frequently changing factors whose origin may be independent of the river barrage. These can occur prior to or after construction and consist of already or not yet observed changes and effects which can result in new ecological and/or economic benefits or losses. From either the scientific or the policy viewpoint, it is mostly the theoretical possibility of the latter that represents an issue, including the practical interpretation and management of the drawbacks involved, either quantitatively or qualitatively. This concept is the so-called engineering risk, which is not only economic but also ecological.

In connection with the operation of the Bos-Nagymaros barrage complex there are primarily two fields for which the scientific formulation of further complex tasks is required.

The identification and monitoring of changes and impacts appearing after the start of operation, in different parts of the area. These are the changes in the state of environmental processes which reduce or increase the natural and social value of water-, soil- and/or land-use.

The objectives and tasks of the monitoring system of the Bos-Nagymaros barrage complex and the basis for its areal distribution and organizational frames have been defined by commissions of the National Authority for Environmental and Natural Protection and by National Water Authority.

A network for the permanent monitoring of the initial state before construction and of the process of changes enabling prediction of the social risks and the potential ecological and economic losses and benefits must be established. In order to set up this network its objectives must be defined. These include:

- (a) selection of phenomena which, according to present knowledge, by measurements, observation or investigation (calculation, estimation, interpolation, extrapolation) are likely to have some impact on the historical, ecological, technological, economic, aesthetic, sociological and political values of the area affected;
- (b) determination of geographic points, lines, areas where these phenomena should be observed;
- (c) elaboration of methods of observation and data recording;
- (d) elaboration of methods for on-site data checking and data transfer, sectorial data processing;
- (e) central collection, handling and storage of data in a central data base; integrated data processing;
- (f) provision of information for institutions and persons interested in project operation and land-use.

After investigating the organizational possibilities for establishing an observation and information system covering the whole affected area, it was concluded that all the observations could not be performed satisfactorily by a single organization or institution. It is thought that the sectorial institutions engaged at present in similar observations should undertake the future tasks, possibly after suitable enlargement of the observed network.

Data processing for sectorial demands is the task of sectorial institutions as well. New facilities are needed in the field of storing, integrated processing of processed information and the establishment of a single information centre.

The emergence of a human-social-natural risk is becoming more and more apparent in most fields of existence because the number of factors and interactions involved has increased and their incidence grown.

The time gained by faster and more certain recognition of phenomena and processes can be devoted to the formulation of social responses and the organization of actions for the reduction of possible losses or a more complete exploitation of possible benefits. At all stages it is important to ensure that all concerned by the impacts are kept fully informed of the possible options.

For a successful implementation and operation of a co-ordinated information system aiming at the efficient use and development of the affected area it is essential to understand the part played by human factors; these include not only the experts employed in the

centres of decision and management, in the institutions of research, planning and construction and in the system of councils but also the hundreds of thousands of people who live or will live in the area.

The recognition of local, sectoral and central interests and their rational co-ordinated representation is a permanent task of professionals and politicians. There are many examples to show that the quantitative and qualitative evaluation of actions which transform the environment may differ.

The democratic atmosphere of open debates, reliance upon international experience and Hungarian science and expertise together should guide us down the relatively narrow path running between dilettantism and voluntarism.

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PAPER 7

EFFECT OF LONG-TERM CAPACITY RESERVOIR ON LARGE ALLUVIAL RIVER WITH SPECIAL REFERENCE TO ASWAN HIGH DAM OF EGYPT

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I. Background

The River Nile, its water and sediment play a great role in the life of Egypt. The river which flows northwards has two main hydrological characteristics:

- 3-month flood season from August to October with muddy water;
- 9 months of low flow and clear water.

The Nile Valley has been formed in the north-eastern desert of Africa, where the suspended solids have been deposited as a rich alluvial soil.

The suspended load of the Nile drew the attention of the scientists who accompanied Napoleon to Egypt in the eighteenth century and who estimated, in their studies of the suspended load, that the average annual rate of deposition amounted to 1 mm. Recent studies by the Hydrological Department of Egypt have confirmed this figure, and it is generally accepted that the annual deposition rate is 0.9 mm. on both river bed and valley. This represents 7 percent of the annual average suspended load which is equal to 134 Mt per year. The remainder of the suspended solids is transported to the Mediterranean Sea by the flood.

The main sources of suspended matter are the Atbara and the Blue Nile, two main tributaries of the Nile (Figure 1) which bring down the eroded surface soil of the Ethiopian mountains during the rainy season from July to September.

In order to introduce perennial irrigation in Egypt, many hydraulic structures have been built across the Nile.

Since the Nile is an alluvial river and its yearly flood is loaded with suspended solids, the side effects of Aswan High Dam on the river's natural regime have become evident amongst which, hydro-chemical effects can be considered to be indirect.

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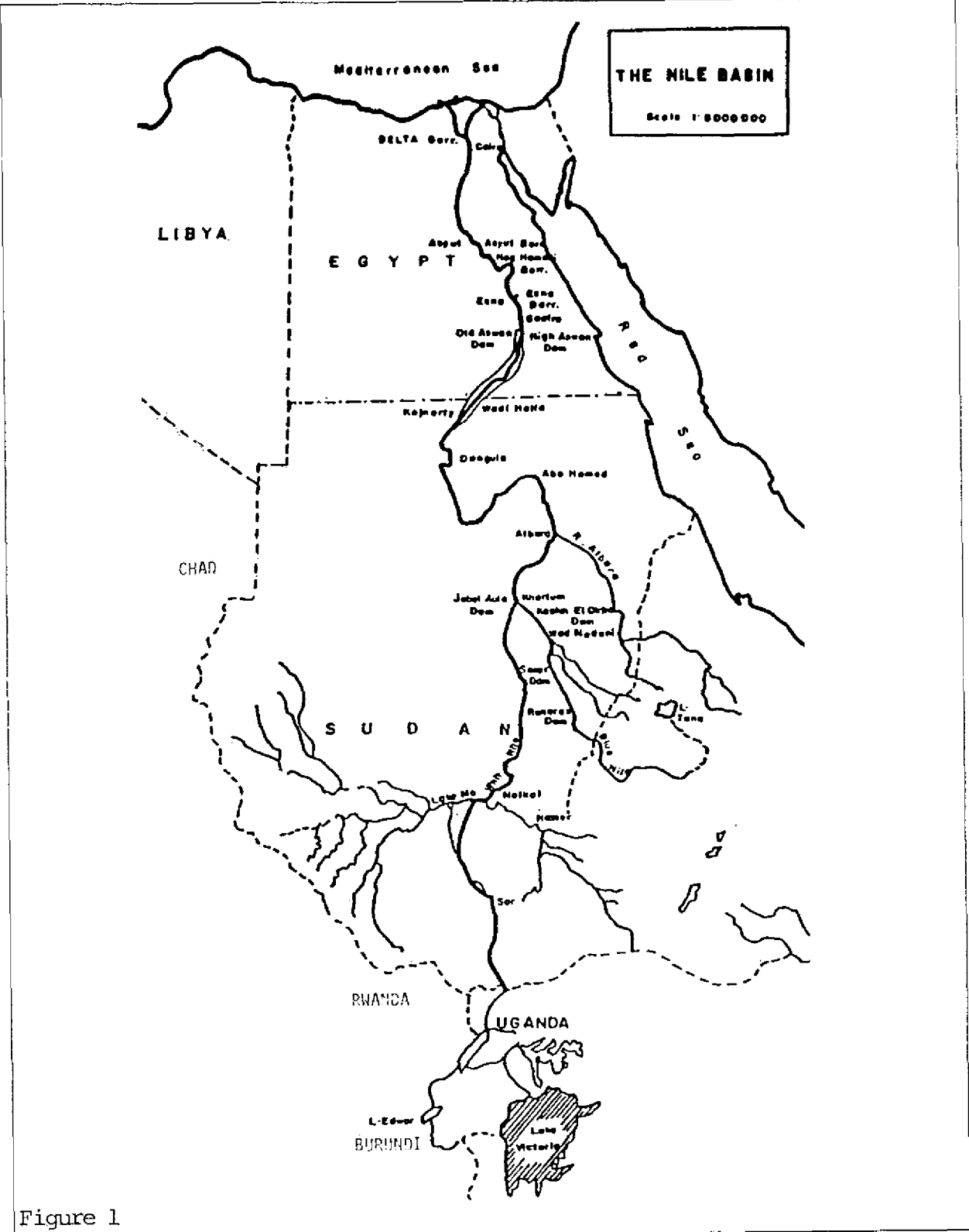


Figure 1

These are not due to the construction of the dam, but mainly result from improper planning of the full use of such a big project in a developing country.

All the major hydraulic structures such as the Old Aswan Dam, the Aswan Low Dam , Esna Barrage, Naga Hammadi Barrage, Asuit Barrage, Delta Barrage and many others, were designed and built in such a way that they passed all the suspended solids carried by floods along the river course to the sea. These structures were designed for seasonal storage and water management. In other words, they only had a very limited effect on the natural hydrological regime of the river.

Many problems occurred as a result of the suspended load such as:

- time required for filling Old Aswan Reservoir in order to avoid silting in view of its limited storage capacity.
- The irrigation and drainage networks of Egypt were affected by sediment deposition, decreasing their efficiencies unless they were cleared every year.
- The main river was affected by dangerous local scour as well as sediment deposition and as a result, river training works were required.
- Investigations were carried out to solve these problems but the results were not always satisfactory.

Due to explosion of population in Egypt and the increased need for agricultural lands, the Aswan High Dam project became essential for the continuance of Egypt's development and has been a turning point in the modern history of Egypt. The dam, a rockfill structure was built on the Nile at Aswan, 953 km south of Cairo. It has been accompanied by several advanced measures in various stages of development all of which are of paramount importance to national progress.

Water Resources

After completion of the dam, Egypt increased its annual share of the Nile water from 48 to 55.5 Gm³, and Sudan increased its share from 4 to 20 Gm³. These quantities are guaranteed for 100 years.

Egypt has completed the first phase of the Toshka spillway to divert excess flood water to the Western Desert. This project should make it possible to cultivate some land around the Toshka depression and in the New Valley when a sufficient volume of water has been stored in the depression in the Western Desert.

After construction of the High Dam, Egypt and Sudan began the comprehensive study of further projects on the Upper Nile, aimed at increasing available water resources for the benefit of both countries. The first project (Jongli Canal) is now under construction, and will be completed late in 1988. 8 or 9 Gm³ will be gained annually by reducing evaporation losses by diverting the water through Jongli canal instead of flooding the Sudd region.

Irrigation

For the first time enormous quantities of water which used to flow to the sea have become available for cultivation of additional Sahara lands sufficient for the reclamation of

1.5 Mha. More than 400 000 ha are already cultivated and the process of reclaiming lands is continuing. Moreover, 400 000 ha of basin irrigation (one crop/year) have been converted to double or triple cropping.

Agricultural output has increased due to regular supply of water for crops at the right time and in sufficient quantities and the possibility of growing more than one crop each year on the same plot.

Power and Industry

Industry has prospered and progressed due to the increased availability of electrical energy (10 GWh) produced by the High Dam and Aswan power station. Many industrial enterprises have been constructed in the Nile Valley. Other power stations have been constructed on the river and energy is now available not only for industry but also for domestic and farm use which together account for 50 percent of the national consumption.

River Navigation and Tourism

The new river regime has led to a rapid growth of the volume of goods and tourists transported on the Nile and on the High Dam Lake, the cost of river transportation being very competitive compared to the others.

Urban and Rural Development

Urban and rural development have benefitted from the availability of power together with rapid industrial and agricultural development.

Flood and Drought Protection

During the early stages the High Dam played a great role in protecting Egypt during high water years of 1964, 1967 and 1975, whilst supplying Egypt and Sudan with sufficient water during the drought years of 1972, 1979, 1982 and 1984. There is no doubt that Egypt was saved from the severe drought of 1984, when its water requirements were met by the 500km long reservoir.

The multipurpose nature of the High Dam has brought about a complete change of the natural hydrological regime of the river over a distance of 50 km upstream and 1 200 km downstream of the dam.

The effects of a seasonal storage reservoir are completely different from those of a pluriannual storage reservoir on an alluvial river like the Nile. The studies carried out in Egypt during the period 1902-1986 will be examined here.

2. Natural River Problems and its Water Structures

The Nile, like all alluvial rivers has its own sediment transport regime. In the past, the hydraulic structures which were built were designed in such a way as to interfere as little as possible with the natural equilibrium. Some of the problems involved are summarized below:

2.1 River Nile Problems

Prior to construction of the High Dam the situation was as follows:

- minimum control of the natural runoff of the river,
- more than 30 Gm³ of fresh water lost annually to the sea,
- for lack of regulation storage any projects on the Upper Nile to increase the annual runoff would have been of little value as half of the expected increase would have arrived at flood time,
- during the annual flood, river bank erosion occurred and national programmes for river training and bank protection were undertaken annually,
- most irrigation and drainage canal networks as well as pumping station inlets suffered from deposition of suspended sediment, which reduced their efficiency. Annual programmes for canal dredging restored normal flow capacities,
- annual dredging costs were high,
- sandy islands appeared while others disappeared within the river channel after each flood season,
- annual programmes were executed to construct river training devices such as spurs, submerged dykes and revetments for protection against bank erosion and undesirable deposition of sediment load,
- it was not possible to cultivate the permanent islands due to submersion during the flood season,
- no energy was produced at existing hydraulic structures. Production of energy at Aswan power station ceased during the flood season,
- navigation routes changed annually, which affected the movement of vessels whose efficiency was low due to small draughts,
- land for rice cultivation was restricted to an area based on the forecast annual flood water. The area varied between 80 000 and 140 000 ha, and it was not possible to go beyond this limit,
- it was not possible to reclaim new lands because the water stored in Aswan reservoir was limited to 5 100 Mm³,
- basin irrigation (400 000 ha) in Upper Egypt did not permit the production of more than one crop,
- in drought years water for irrigation was insufficient, leading to an economic catastrophe in 1914,
- agricultural and industrial growth were limited with negative consequences for the national production and income,

- there was no possibility of evacuating drainage water in Upper Egypt directly to the Nile during the flood period,
- during periods of very high water agricultural lands close to the river were submerged and many crops damaged.

2.2 Large Hydraulic Structures on the Nile

Prior to the construction of the High Dam some large hydraulic structures had been built either to store a limited volume of flood water or to raise water levels during the low water season. These structures are described below:

Old Aswan dam, a concrete gravity dam, was built at Aswan between 1898 and in 1902 whose original storage capacity was 1 000 Mm³ for a maximum head of 26 m. This capacity was increased to 5 100 Mm³ for a total head of 39 m. The dam is built on a rock foundation

Asuit Barrage was built across the Nile in 1902, 549 km downstream of the Old Aswan Dam to raise water levels upstream for irrigation purposes. This barrage created a head of 2.5 m later increased to 5 m. head. This brick and concrete dam built on sand is provided with 110 sluice gates.

Esna Barrage was built in 1908 some 167 km downstream of Old Aswan Dam. This dam was intended to raise water levels by 2.5 m for irrigation. Built of brick and concrete founded on sand, it is provided with 120 sluice gates. The head on this barrage was increased in 1948 to 4.9 m.

Naga Hammadi Barrage was built across the Nile in 1910 about 189 km downstream of Esna Barrage. This barrage, built on a sandy foundation, consists of a brick and concrete wall and provided with 100 sluice gates, and raises water levels by 4.5 m for irrigation purposes.

New Delta Barrage was built in 1938 to raise water levels for irrigation. This barrage was founded on sand and provided with sluice gates. The maximum head is 3.8 m.

2.3 Aswan High Dam

In order to overcome some of the problems enumerated above, a multipurpose project was launched, know as the Aswan High Dam.

The problems which have been solved are:

- about 90 Gm³ of pluri-annual long-term live storage has been created in a large reservoir;
- the water requirements of Egypt and Sudan are guaranteed during low water years for a period of 100 years;
- the water resources are controlled and released according to requirements;
- construction of the first of a number of water management projects has started on the Upper Nile (Jongli Canal);

- annual production of 88 TWh of energy;
- regulation and continuation of power production at Old Aswan Power Station improved by streamflow regulation;
- extension of Aswan 1 power station installed capacity of 120 MW;
- control of the discharge and levels of the Nile along the reach between Aswan and Delta Barrage makes it possible to produce power at the barrages on the main river and canals.
- more water is available for extended irrigation area; seasonal irrigation (basin irrigation) in Upper Egypt converted to perennial irrigation, for multi-crop production (400 000 ha);
- drainage networks have been improved;
- river navigation has increased as the river navigation route is nearly stable with a reasonable depth of water all the year long;
- all the Nile shores and islands are under cultivation;
- about 98 percent of the natural sediment load is deposited in Aswan High Dam reservoir;

There is no doubt that the High Dam (HAD) is a turning point in the hydrology of the Nile, as it has completely changed the regime both up and downstream.

A brief description of the Dam follows:

- Rockfill dam, completed in 1968.
- Dead storage is 31.5 Gm³ at 147 m.
- Live storage is 90.5 Gm³ at 175 m.
- Flood protection storage is 46 Gm³ at 182 m.
- River bed level is 80 m.
- Crest level is 196 m.
- Power station with 12 Francis turbines each 175 MW.
- Dam is provided with 2 spillways at 178 m, one diverts 9 260 m³s⁻¹ to the main river, the second is constructed 250 km upstream of the dam to divert 2 890 m³s⁻¹ to the western desert (Toshks Depression).

Although the High Dam has solved some of the problems inherent in the natural regime of the river it has created other side effects associated with the new regime of the river.

3. Side Effects of Hydraulic Structures

The side effects of all structures built before the High Dam were seasonal and local whereas those of the High Dam are permanent and generalized. This is due to the different objectives and the design of the structures.

3.1 General nature of side effects

Side effects resulting from operations of the High Dam can be summarized as follows:

- The length of river between the High Dam and the Delta Barrage is 953 km. (Figure 1). The Damietta Branch of the Nile from Delta Barrage to the Mediterranean, is 255 km long whilst the Rosetta branch is about 245 km long.
- The width of the valley is not uniform and varies from south to north, from 0.3 to 24 km, the narrow stretches being more generally in the south.
- The width of the channel is variable along the reach from Aswan to Delta Barrage. When the river has a single channel the width is 300 m to 650 m but when it braids, with the formation of islands, the channel width varies between 1 200 and 2 000 m. The sinuosity of the stream varies from 1.01 to 1.30 which reflects the stream's straightness in most reaches, while its section shape factor varies from 3 to 4 which shows that the River Nile has the shape of a normal water course.
- There are 220 islands between Aswan and the Delta Barrage or approximately one island every 5 km. All these islands are oval in shape and the soil consists of alluvium transported by the river.
- Bed and bank materials consist of fine sand, silt and clay in the proportion of 30, 30 and 40 percent approximately.
- The flood normally starts at the beginning of August and ends in early November.
- Downstream of Aswan Dam there are no tributaries apart from a few storm drains on the eastern side of the river.

During the flood period, the maximum mean monthly discharge ranges from 10 000 to 11 000 m^3s^{-1} . The maximum daily discharge recorded in 1878 had a value of 13 200 m^3s^{-1} . Peaks of 12 700 and 11 900 m^3s^{-1} were recorded in 1964 and 1954 respectively. In the low season the mean monthly discharge ranges from 400 to 500 m^3s^{-1} .

Silt investigations commenced a long time ago and are continuing. Torrential rainfall which erodes the soil on the mountainous escarpments of Ethiopia causes suspended matter to be brought down with the flood. The peak sediment flow is observed to be 10 to 15 days ahead of the flood peak. The regime of suspended load did not vary in the Nile reach between Aswan and Delta Barrage before construction of hydraulic structures.

The maximum silt concentration varied between 3 000 and 4 000 p.p.m. in August and September, the minimum concentration, 25 to 30 p.p.m., was recorded in April and May.

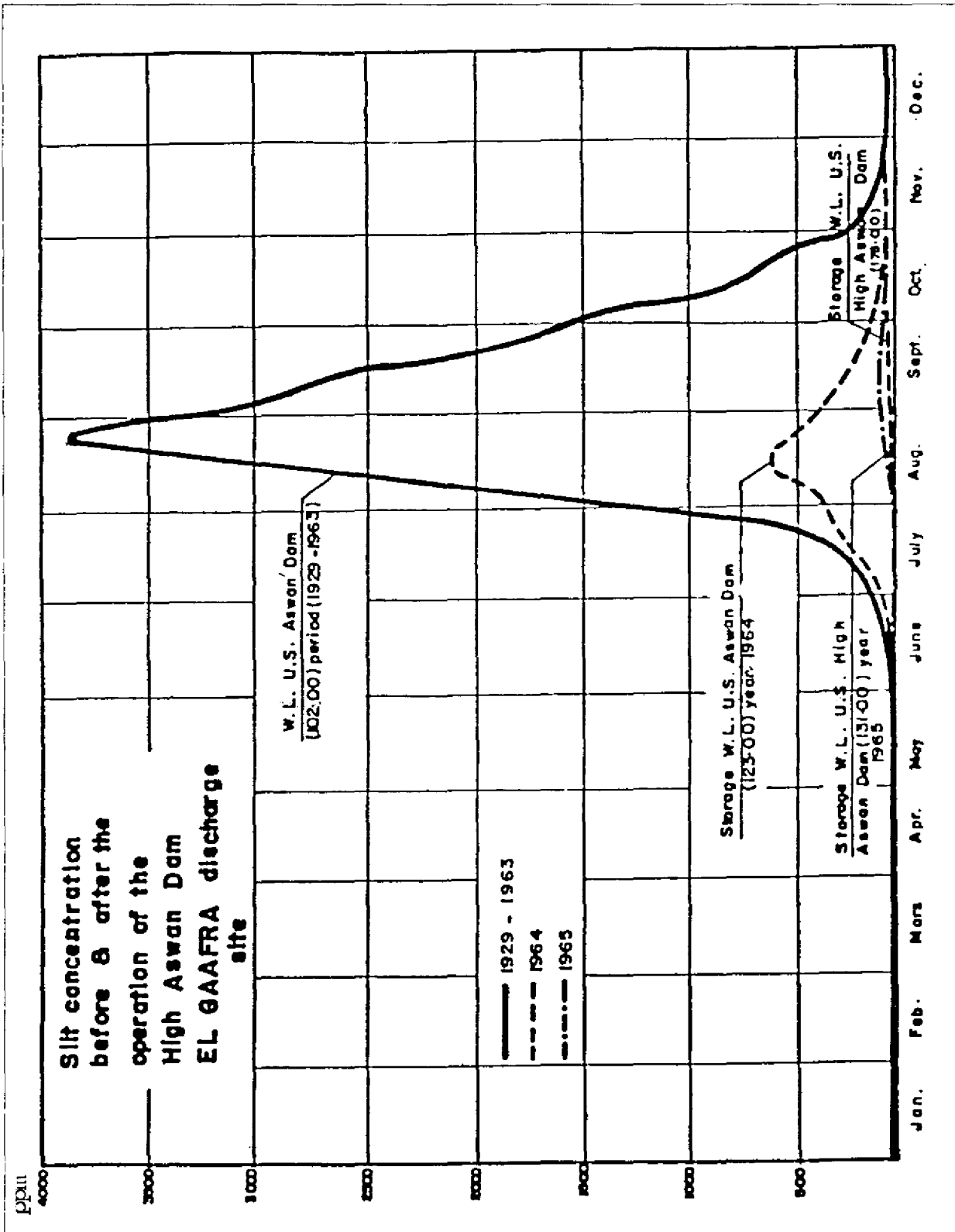


Figure 2

3.2 Effect of Aswan Dam on the Sediment Regime

Old Aswan Dam was operated so as to avoid any deposition of suspended sediment in the reservoir because deposits would have reduced the small capacity of the reservoir.

Following numerous investigations of the characteristics, movement and concentration of the suspended sediment, it was found possible to avoid any sediment deposition within the reservoir during the period 1902 - 1963.

A hydrographic survey made along the backwater curve upstream of the dam showed that the bed levels varied between ± 0.20 and 0.25 m.

The success of this operation depended on a good understanding of the relation between silt concentration and streamflow during flood periods and proper timing of the closure of the sluice gates to store water in the reservoir.

As a result of operating Old Aswan Dam in this way, it was found that the time distribution of sediment discharge had not changed after construction of the dam.

Since the primary function of the High Dam is to store water on long-term basis nearly all the suspended load of the Nile is deposited upstream and only 1.5 percent of very fine matter is now released below the dam, i.e. completely modifying the sediment regime of the Nile (Figure 2).

The suspended solids are deposited downstream of a point situated 150 km from the upstream limit of the backwater curve, i.e. 400 km from the dam. The accumulated sediment has formed submerged hills whose summits appear as islands in the reservoir. Deposition of sediment in the reservoir has been traced by yearly hydrographic surveys, measurements of sediment concentration of the inflow along the reservoir profile and by satellite imagery during flood season. The movement of sediment deposition is very slow and it does not adopt the shape of the dead storage area. The suspended load deposits in the seasonal storage reservoir (Old Aswan Dam) and long-term storage reservoir (High Aswan Dam) are compared in Figure 3.

3.3 Effect of Aswan Dam on River Levels

Operation of Old Aswan Dam being seasonal, the impact on the river regime was seasonal and limited. A hydrograph of river levels at Aswan before and after construction of the Old Dam is shown in Figure 4 illustrating the effect on the river levels. This phenomenon was repeated yearly until the High Dam was constructed.

Due to the long-term storage function of the High Dam the regime of the water levels at Aswan are completely changed. Water levels upstream of the High Dam during the period 1964-1984 are shown in Figure 5.

3.4 Effect of Intermediate Hydraulic Structures

Case (a) Before construction of Aswan High Dam

The intermediate barrages at Esna, Naga Hammadi and Asuit had only a localized effect, (Figures 6). The stage-discharge relationships did not change downstream of these structures, the water level corresponding to a given discharge fluctuated by ± 20 cm during the period prior to the construction of the High Dam.

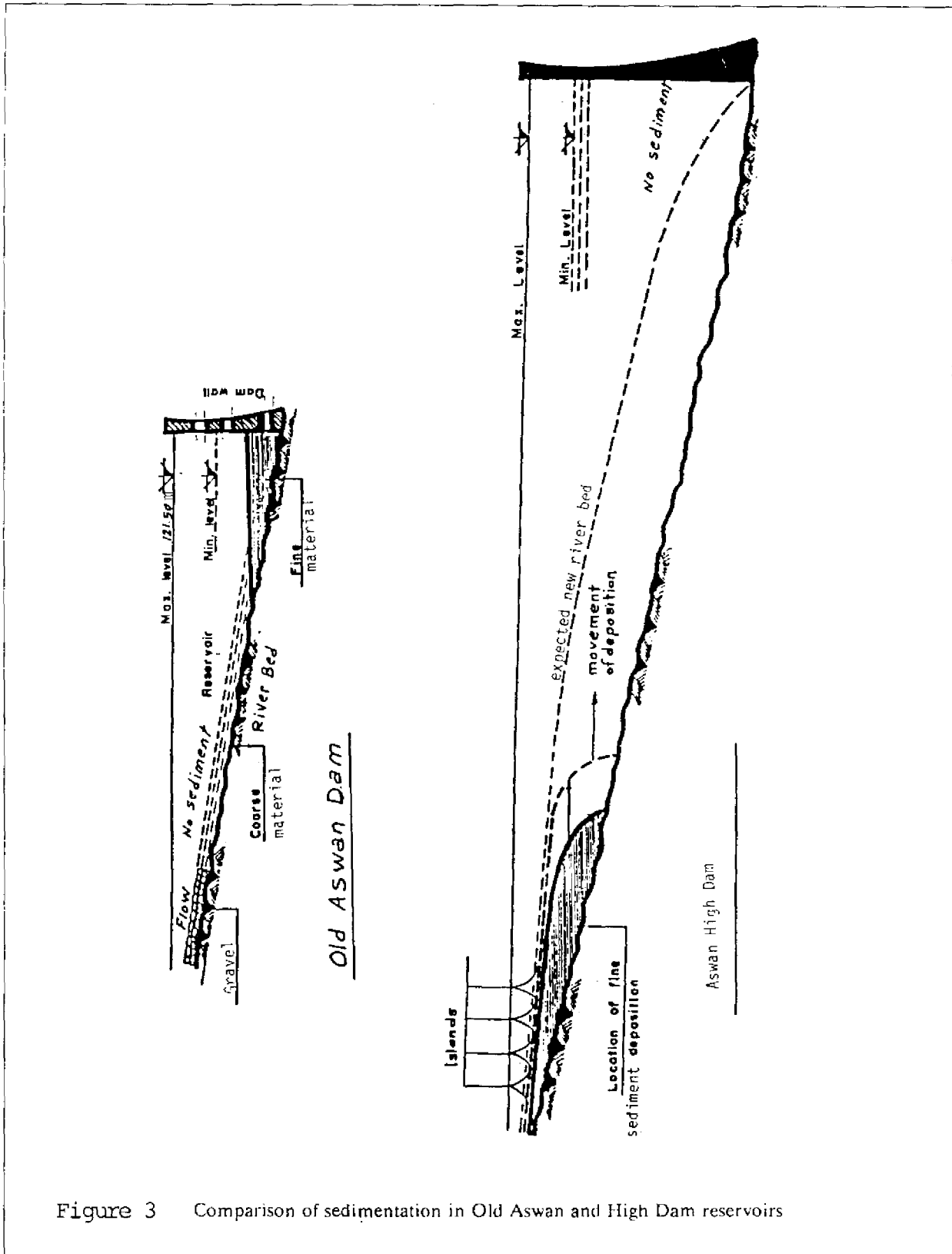


Figure 3 Comparison of sedimentation in Old Aswan and High Dam reservoirs

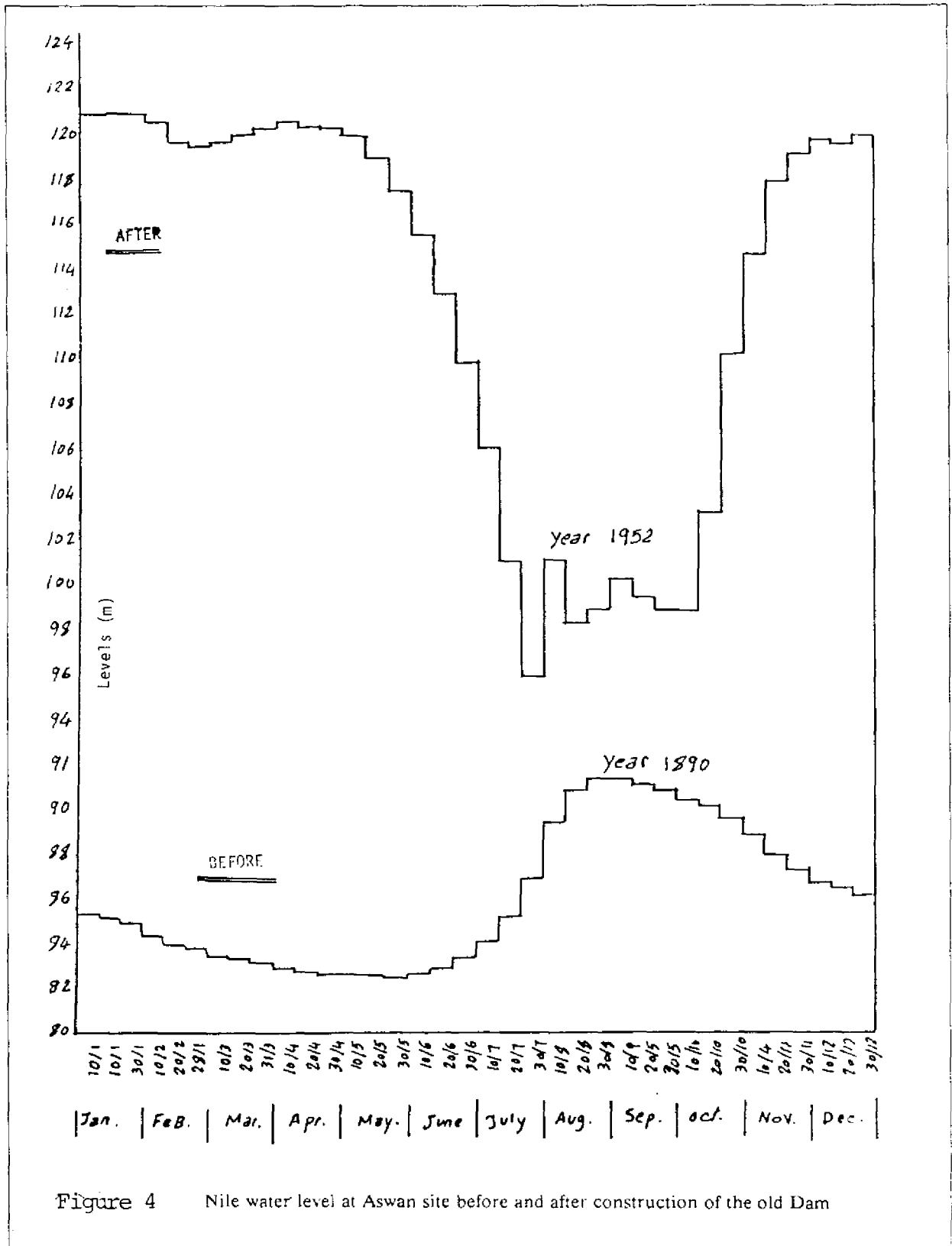


Figure 4 Nile water level at Aswan site before and after construction of the old Dam

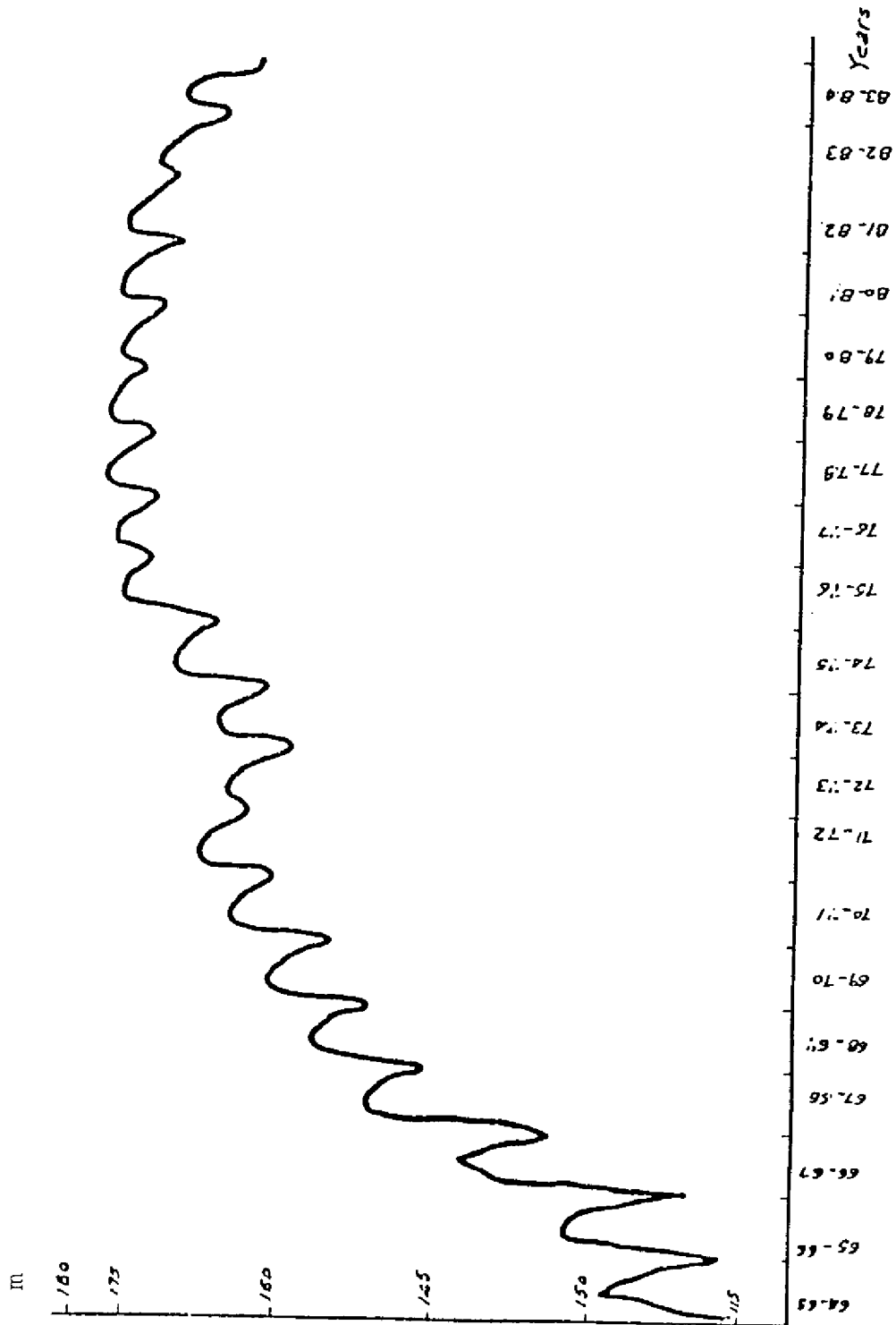


Figure 5 Water levels in High Dam Reservoir (1964-1984)

Some scour holes appeared just downstream of Esna, Naga Hammadi Barrages, but these did not affect either river levels or discharges. Moreover, the intermediate structures did not affect the natural sediment regime of the river.

Case (b) After construction of the High Dam

Due to the almost complete disappearance of the suspended solids in the Nile flow, degradation of the watercourse occurred downstream of the dam, characterized by a fall of water levels of about 1.0 m below each barrage, over the past 20 years.

3.5 Effects of Aswan Dams on River Nile Bank-Stability and Formation of Islands

Before construction of the High Dam, when the river regime was natural, the river banks were stable and erosion occurred only locally and did not represent a general phenomenon. After construction of the High Dam the natural regime of the river was completely changed, generalized river bank erosion took place. A typical case of bank erosion is shown in Figure 6. The cumulated length of eroded banks attains more than 550 km after 20 years.

110 new islands have been formed within the river channel and 100 submerged islands are in formation. This phenomenon is due to increased movement of bed load.

Both bank erosion and streambed degradation phenomena are serious negative side effects resulting from reservoir operation.

3.6 Effect of Aswan Dams on Nile Water Quality

Total dissolved solids (TDS) in water are used as an indication of water quality. Any change of concentration of TDS reflects the impact of the construction of the dams.

Before and after construction of Old Aswan Dam, TDS varied each year from a minimum of 120 p.p.m. in September and a maximum of 230 p.p.m. in June. After construction of the High Dam the water released from the reservoir has a TDS concentration which varies little over the year. In 1969 (construction completed) TDS concentration was 170 p.p.m., increasing to 189 p.p.m. by 1984, a rate of increase of one p.p.m. per year. This rate of increase will change due to filling and emptying of the reservoir during the coming years.

4. Conclusion

The impact of large hydraulic structures on the river regime differs according to:

- a. Function of the structures.
- b. Design of the structures.
- c. Suspended sediment inflow.
- d. Nature of the river bed and bank materials.

In the case of the Nile, seasonal regulation structures have a limited effect on the natural river regime. In the case of a multipurpose project, if all the objectives are to be

achieved, the natural regime of the river must be modified and it is necessary to take steps to overcome the resulting negative side effects

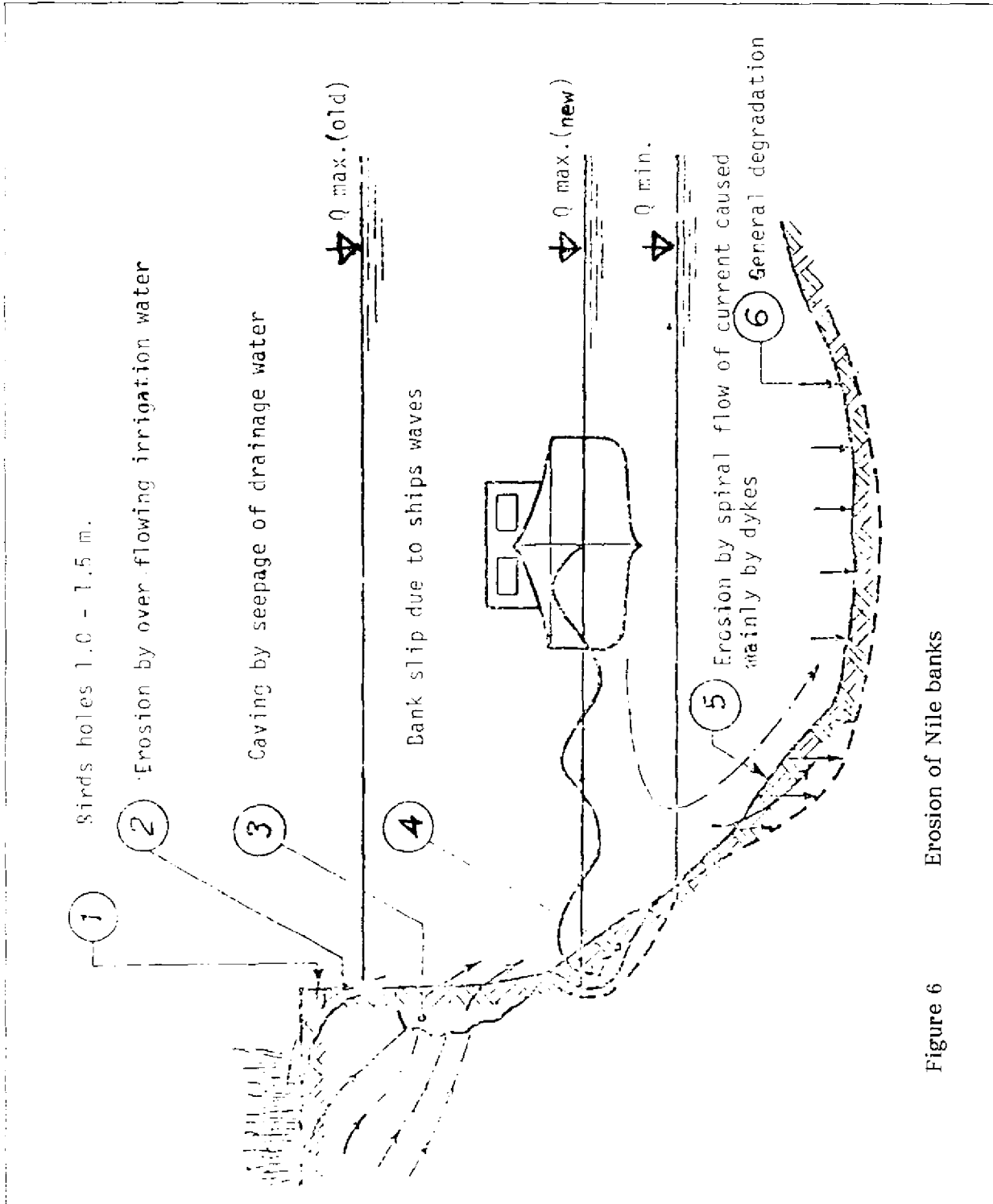


Figure 6 Erosion of Nile banks

PAPER 8

APPORTS DE LA SIMULATION DE FONCTIONNEMENT DES AMENAGEMENTS A L'ETUDE DE LEUR IMPACT SUR L'ENVIRONNEMENT

Exemple de la MEJERDAH - Tunisie

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Résumé

Le projet d'aménagement des eaux du nord de la Tunisie a donné lieu à l'élaboration d'un modèle mathématique de fonctionnement du système d'eau chargé d'alimenter en eau potable les grandes villes, d'irriguer 110 000 hectares de terres cultivées, et de satisfaire aux besoins de deux complexes industriels.

La simulation met en évidence:

- l'abondance des besoins et la qualité requise de l'eau distribuée face à celles des ressources,
- l'altération des possibilités de stockage du système par l'envasement progressif des retenues,
- l'altération de la qualité de la ressource en eau de surface par récupération des eaux de drainage des périmètres irrigués,
- la modification du régime d'alimentation en eau douce du lac Ichkeul, Parc national, en le privant d'une partie de ses apports naturels.

En 1983, le Ministère de l'Agriculture de la République Tunisienne (Direction des Etudes et des Grands Travaux Hydrauliques) a chargé l'ORSTOM d'une étude des ressources en eau du bassin de la Mejerdah, de l'Ichkeul, de l'extrême nord, et de leur utilisation optimale⁸. Elle fait suite à deux études antérieures (1972 et 1978) portant déjà sur la gestion des ressources en eau de cette région. Une telle succession résulte de la démarche

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⁸ Aménagement des ressources en eau du Nord de la Tunisie. Modèle EAUTUN-3, ORSTOM-DEGTH, décembre 1984

par étapes, suivie par les responsables tunisiens dans l'analyse et la réalisation de l'Aménagement prévu par le Plan Directeur des Eaux du Nord, établi entre 1970 et 1974, destiné à satisfaire en même temps des demandes croissantes en eau potable pour les grandes agglomérations, et en eau agricole pour l'irrigation. Ces différentes étapes correspondaient en fait à une approche de plus en plus détaillée de l'Aménagement, liée à une évolution sensible dans sa conception par suite de nouvelles considérations techniques et socio-économiques. Elles se justifient aussi par la nécessaire prise en compte des résultats des études récentes conduisant à une mise à jour des connaissances. C'est le cas pour l'information hydrologique qui continue à être régulièrement recueillie et permet d'affiner l'évaluation que l'on fait de la ressource en eau.

Notre présente intention n'est pas d'exposer ici le modèle EAUTUN-3 de simulation de fonctionnement de ce grand système d'eau, mais d'utiliser certains des résultats qu'il apporte pour souligner une partie des effets que peut avoir sur l'environnement la mise en service d'un grand aménagement comme celui-ci.

1 Le Projet d'Aménagement

1.1. Son contexte géographique et économique

L'emprise géographique de l'Aménagement s'étend sur la partie de la Tunisie située au nord de la Grande Dorsale, de direction SW/NE, qui traverse le pays depuis la frontière algérienne à l'ouest jusqu'au Cap Bon à l'est. Une extension secondaire du projet est envisagée vers le sud pour l'alimentation en eau potable de la région de Sfax.

Le nord tunisien, dont la superficie ne représente guère que 18 pourcent de l'ensemble du pays, concentre une grande partie de l'activité économique et sociale. Sa population représente environ la moitié de la population totale de la Tunisie. Le secteur économique privilégié reste l'agriculture. La politique mise en place vise à l'autosuffisance alimentaire par l'intensification des cultures traditionnelles et le développement de la pratique de l'irrigation afin d'améliorer la productivité. Le secteur industriel est en croissance constante autour de quelques centres où se développent des industries manufacturières (Tunis, Bizerte) malgré des ressources énergétiques et minières peu abondantes (phosphates de chaux essentiellement). Enfin, le tourisme est devenu une activité importante, avec un fort développement à proximité de Bizerte et de Tunis, et surtout dans la région de Cap Bon (Hammamet, Nebeul).

Sur les Hauts Plateaux du sud de la région prédominent la culture des céréales et l'élevage extensif des ovins. Localement, dans les plaines de Siliana et du Kef l'arboriculture se développe ainsi que les cultures maraîchères.

En moyenne Mejerdah et dans la zone de Mateur s'étendent de grandes exploitations agricoles qui pratiquent l'élevage bovin et la culture des plantes fourragères, des céréales, des légumineuses, et de la betterave à sucre.

Dans la région montagneuse et bien arrosée qui borde la Méditerranée, les sols sont peu fertiles et l'on y pratique traditionnellement l'élevage extensif des bovins et la culture des céréales.

Dans le Tell Oriental constitué des plaines de Bizerte, de Tunis et du Cap Bon, les petites et moyennes exploitations familiales se développent dans la culture des légumes, des arbres fruitiers et de la vigne. Depuis plus de 25 ans, l'équipement de périmètres irrigués se

poursuit dans la basse vallée de la Mejerdah sous l'égide de l'Office de Mise en Valeur de la Vallée de la Mejerdah. Dans les plaines de Mornag et de Soliman, l'exploitation des ressources en eau locales, tant superficielles que souterraines, est à l'origine de la grande extension des cultures maraîchères et fruitières, à tel point que près de 80 pourcent des agrumes tunisiens sont cultivés dans cette région du Cap Bon. Mais l'épuisement d'une partie de ces ressources par surexploitation des nappes et ensablement de retenues de stockage pose maintenant un grave problème de sauvegarde de ces cultures. Région à très forte concentration de population avec les villes de Tunis, Bizerte, Nebeul, le Tell Oriental est aussi le siège d'une importante activité touristique, grande consommatrice d'eau, à laquelle s'ajoute un récent développement industriel.

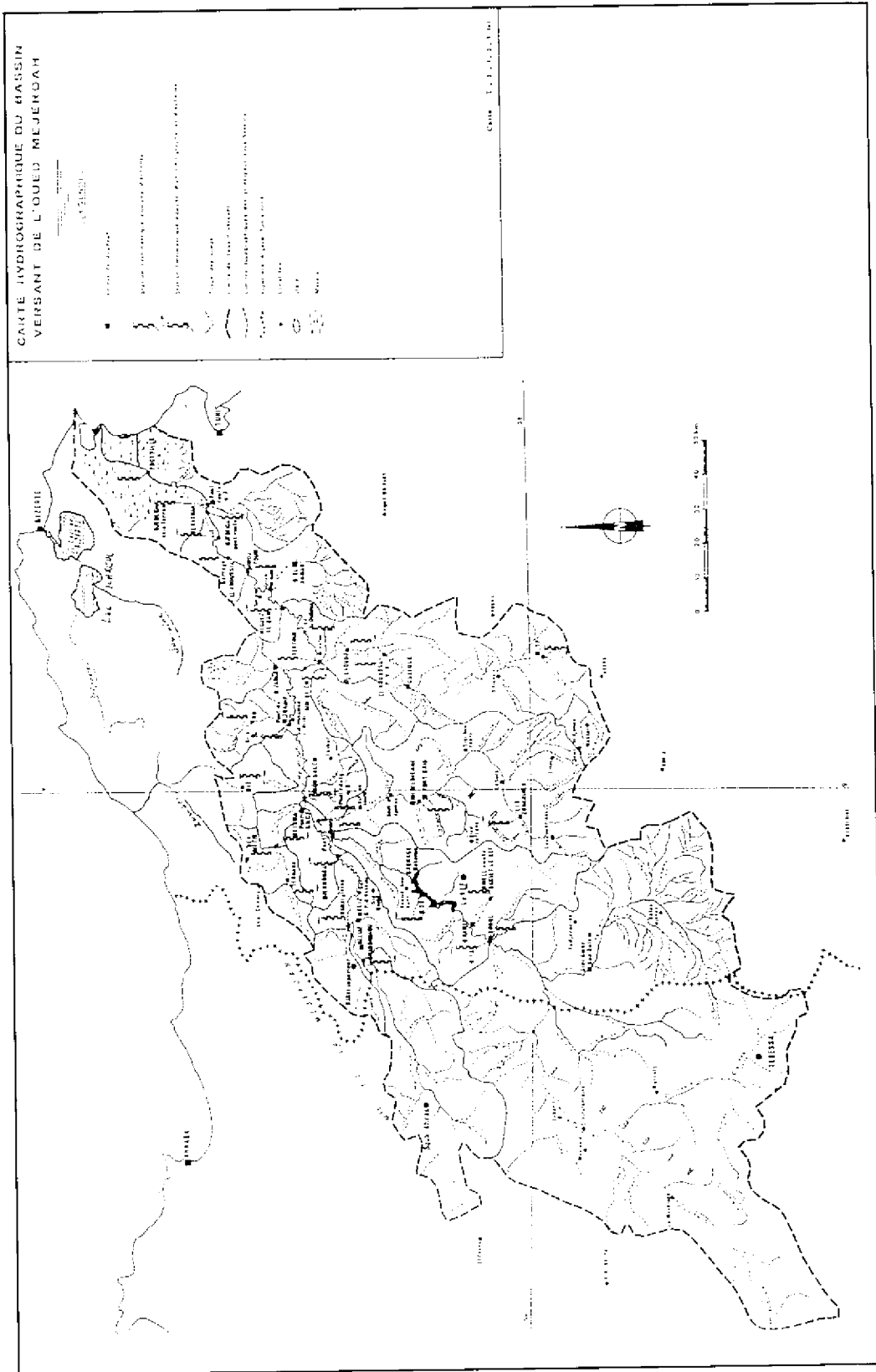
1.2 Les objectifs généraux et les caractéristiques du Projet

Le projet consiste à assurer la meilleure utilisation possible des ressources en eau disponibles de façon à combiner la satisfaction des besoins en eau à usage domestique pour l'eau potable, agricole pour l'irrigation, et industriel pour les complexes phosphatiers.

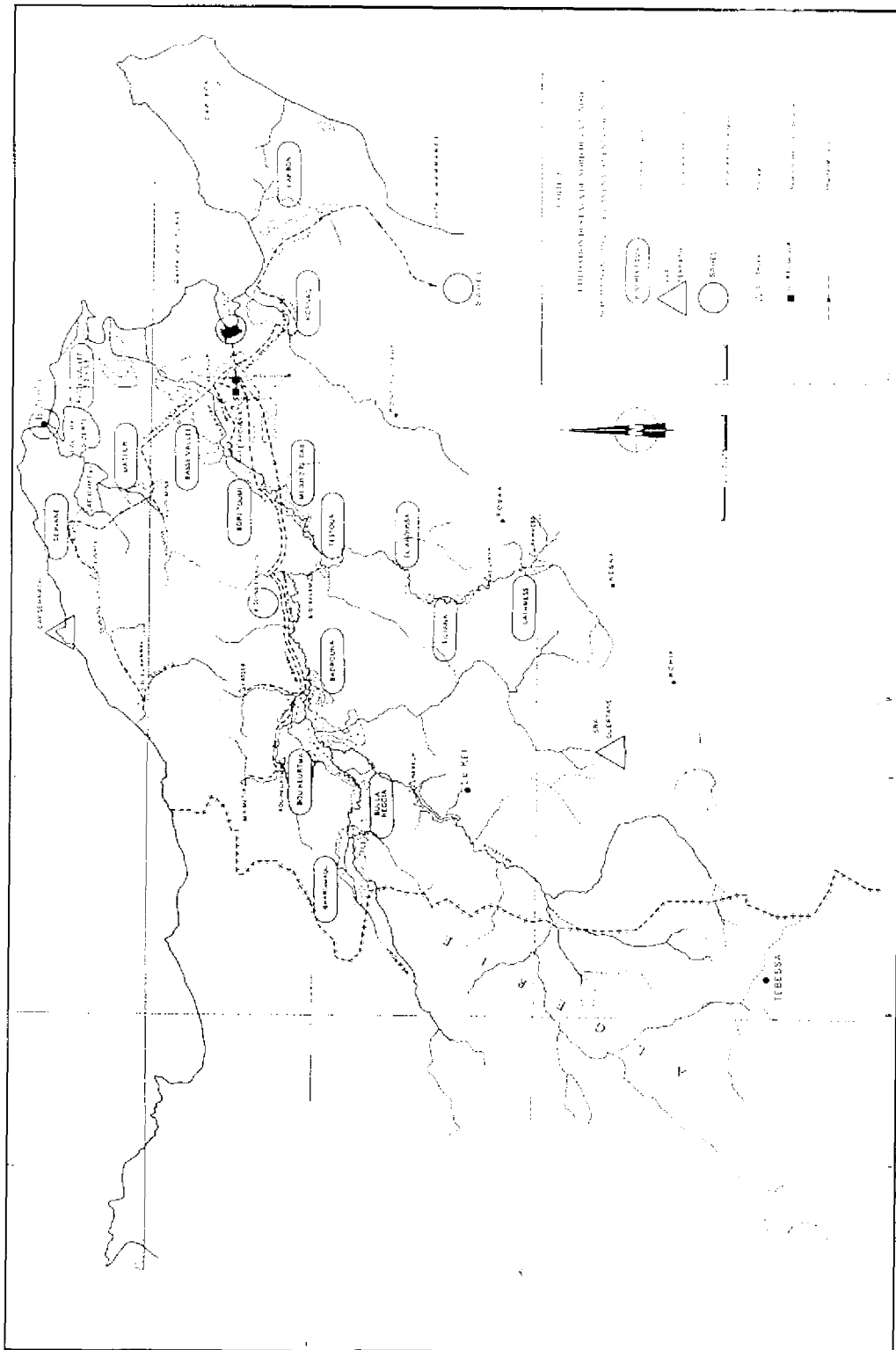
La priorité des utilisations a été donnée à l'eau potable des grandes agglomérations : Tunis et la région du Cap Bon, ainsi que Bizerte. Cependant, il s'agit d'abord d'un projet à vocation agricole par l'importance des besoins à satisfaire, car l'agriculture demeure l'activité économique du pays la plus grande consommatrice d'eau avec plus de la moitié de la demande totale. L'utilisation des ressources mobilisées à des fins industrielles n'a été envisagée que récemment et ne représente qu'une faible part, 9 pourcent de la demande totale.

Une autre particularité du projet tunisien est la prise en considération des problèmes de qualité de l'eau à distribuer selon l'usage auquel elle est destinée. Les eaux de nombreux oueds sont en effet fortement chargées en sels dissous (chlorures, sulfates) avec des teneurs variables selon la nature géologique de leurs bassins d'alimentation. L'aspect qualitatif de la ressource est une contrainte supplémentaire à respecter, d'autant que l'incidence du facteur salinité, déjà importante pour l'irrigation des cultures devient capitale pour l'alimentation en eau potable. Dans ce cas en effet, la salinité de l'eau ne doit jamais excéder une valeur maximale imposée. Etant donné la rareté des eaux douces de bonne qualité essentiellement localisées dans la zone nord, une des fonctions principales de l'aménagement est donc d'assurer le transfert puis le mélange adéquat d'eaux de provenances différentes afin de satisfaire en quantité les besoins exprimés en respectant les critères de qualité souhaités pour l'irrigation et imposés pour l'eau potable.

En marge du projet, il faut enfin signaler qu'à la plupart des barrages-réservoirs existants ou envisagés, sont associées des usines hydroélectriques dont la production n'est toutefois considérée que comme un sous produit de l'aménagement et de ce fait n'a pas été intégrée dans la modélisation du fonctionnement du système. De même, le rôle des barrages dans la protection contre les crues est encore une autre fonction de l'aménagement dont il n'a pas été tenu compte bien que le barrage de Nebeul par exemple y tienne une place essentielle.



Simulation de Fonctionnement des Aménagements



1.3 Les ressources en eau

A l'exception de l'exploitation des nappes souterraines de Ghardimaou et de Bulla Reggia (moins de 20 Mm³ par an), les ressources proviennent des eaux de surface des bassins de la Mejerdah, de l'Ichkeul, et du Zouara à l'extrême nord. Les apports naturels globaux de ces bassins sont estimés à 1 458 Mm³ en année moyenne, ce qui représente plus de 70 pourcent du potentiel en eau de surface de toute la Tunisie.

Le bassin de la Mejerdah, d'une superficie de 23 260 km² dont 7 600 km² sont en territoire algérien, fournit 68 pourcent du total soit 987 Mm³ avec une salinité moyenne de 1,3 g l⁻¹. D'une façon générale, les affluents du versant sud (rive droite) ont une charge saline assez élevée qui dépasse 1,5 g l⁻¹ tandis que les affluents du versant nord (rive gauche) ont des eaux plus douces dont la salinité moyenne n'atteint pas 1 g l⁻¹.

Les oueds Joumine et Sejnane font partie du bassin de l'Ichkeul qui, par le Lac de Bizerte, se jette en Méditerranée. Le bassin du Joumine, 448 km² au site du barrage, fournit en année moyenne 145 Mm³ d'eau d'assez bonne qualité dont la salinité moyenne est de 0,79 g l⁻¹. Quant au bassin du Sejnane, 324 km² au site du barrage, il fournit en année moyenne 104 Mm³ d'une eau de bonne qualité dont la salinité moyenne est de 0,64 g l⁻¹.

Enfin, le bassin de l'oued côtier méditerranéen qu'est le Zouara, avec une superficie de 880 km² au site du barrage de Sidi el Barrak, fournit en année moyenne 222 Mm³ d'une eau de salinité moyenne de 0,78 g l⁻¹.

En résumé, les apports moyens interannuels se répartissent donc ainsi: 987 Mm³ dans le bassin de la Mejerdah, dont environ 260 Mm³ proviennent du territoire algérien, 249 Mm³ dans le bassin de l'Ichkeul et 222 Mm³ dans le bassin du Zouara. Mais ces apports sont irréguliers d'une année sur l'autre puisque les valeurs de fréquence décennale faible et forte sont dans la proportion de 1 à 3,5.

1.4 Les besoins en eau

Un inventaire aussi complet que possible des besoins potentiels futurs en eau domestique, agricole et industrielle a été fait par les spécialistes concernés sur la base de la situation actuelle et d'hypothèses réalistes de développement démographique et socio-économique de la région. A partir de cet inventaire furent établis les programmes de demandes relatifs aux différents points de prélèvement d'eau dans ce système.

Il s'agit de demandes complémentaires à satisfaire, évaluées à partir des besoins bruts dont on a déduit la participation des ressources locales éventuelles comme les précipitations tombant sur les périmètres irrigables, et qu'on a soumis à l'efficacité toujours imparfaite des systèmes d'alimentation et de distribution. Certaines demandes correspondent à des besoins quasiment incompressibles comme l'eau potable ou la sauvegarde de cultures existantes, tandis que d'autres dépendent des choix qu'on peut faire notamment sur l'extension des périmètres irrigués, et sont donc susceptibles d'être modifiées.

Chacun de ces programmes de demandes en eau est établi de façon évolutive pour différents horizons de la prospective et correspond à un scénario envisageable qui pourra être testé à l'aide du modèle de simulation.

Les besoins en eau potable concernent les grandes villes de Tunis-Cap Bon, de Bizerte, l'extension du réseau vers Sfax, ainsi que les "besoins en route" le long de la conduite qui

alimente Tunis depuis la retenue de Ben Metir. Les besoins sont partiellement satisfaits à partir des ressources locales. Les demandes complémentaires adressées au système Mejerdah-Ichkeul-Zouara, sont de 124 Mm³ en 1985 et devraient atteindre 423 Mm³ en l'an 2000. La demande en eau potable pour Tunis et Bizerte est accompagnée d'une contrainte de qualité, la salinité de la fourniture ne devant pas excéder 1 g l⁻¹.

Le projet doit permettre de développer l'irrigation le long de la vallée de la Mejerdah, de ses affluents, et dans les secteurs agricoles de l'Ichkeul, de Mornag, et du Cap Bon. Il s'agit de périmètres irrigables déjà équipés ou en voie de l'être, soit des extensions ou de nouveaux périmètres prévus par le Plan Directeur, ou faisant l'objet de projets locaux de mise en valeur comme Bou Heurtma ou le Haut Siliana. La superficie totale des terres irrigables concernées représente près de 110 000 hectares dont la demande annuelle potentielle en eau d'irrigation serait de l'ordre de 750 Mm³. Mais les solutions envisagées ne considèrent qu'une réalisation partielle de ces possibilités de mise en valeur, à quoi correspond un volume global de demandes de 590 Mm³ par an. La satisfaction de ces demandes agricoles n'impose pas le respect d'une contrainte de salinité. Cependant, le Plan Directeur des Eaux du Nord préconise que la charge saline de l'eau utilisée pour l'irrigation n'excède pas 1,8 g l⁻¹.

Les besoins en eau industrielle, sans contrainte de qualité au moins au niveau du prélèvement, correspondent au projet d'implantation de deux nouveaux complexes industriels liés à l'exploitation et au traitement des phosphates, l'un à Sra Ouertane qui sera alimenté à partir de la retenue de Nebeur, l'autre à Cap Serrath qui recevra l'eau du Zouara retenue au barrage de Sidi el Barrak. Il est prévu qu'en l'an 2000 la demande totale en eau industrielle de ces deux complexes sera stabilisée au niveau de 100 Mm³ par an.

En récapitulant ces demandes en eau on retient : de 125 à 425 Mm³ pour l'eau potable, 590 Mm³ pour l'eau d'irrigation et 100 Mm³ pour l'eau industrielle, soit un total de 815 à 1 115 Mm³ alors que, rappelons-le, les apports bruts en eau de surface de tout le système sont de 1 459 Mm³.

2 Fonctionnement des Retenues de Stockage

Etant donné l'importance des besoins en eau face au potentiel hydraulique de tout le système, il est clair que c'est seulement par un projet d'ensemble qu'on peut espérer répondre de manière satisfaisante à ces demandes. Il est également clair que cet aménagement se compose de projets partiels répondant à des problèmes locaux spécifiques, dont la réalisation s'échelonne sur plusieurs dizaines d'années, mais que l'économie de cette eau précieuse passe par une gestion coordonnée de tout l'ensemble.

En effet, mobiliser les ressources que recèlent les apports bruts des cours d'eau demande qu'on construise de nombreux équipements et en particulier des barrages-réservoirs. Une douzaine de ces ouvrages font partie de l'Aménagement; certains existent depuis plus de 30 ans, d'autres sont plus récents, d'autres encore sont en construction et les derniers sont en projet. Il convient alors de garder présent à l'esprit que ces réservoirs s'ensavent au fil des ans et que leur capacité de stockage diminue progressivement depuis le jour de leur mise en service. Le taux d'ensablement est variable, de 0,5 à 5 pourcent par an et dépend en même temps des volumes liquides et solides des apports bruts et du volume de la retenue de stockage. La petite retenue de Lakhmess, mise en service en 1966 devrait être totalement comblée de sédiments aux environs de l'an 2005 et ne sera alors plus en état de remplir sa fonction après 40 ans de services. En générale, le taux annuel d'ensablement est compris entre 0,7 et 1,1 pourcent. Cela signifie que la capacité

de stockage de l'ensemble des ouvrages qui doit atteindre 1 290 Mm³ en l'an 2000 se voit réduite par envasement de 12 à 13 Mm³ par an. Il est donc clair, qu'à défaut de pouvoir débarrasser les réservoirs de ces sédiments, et pour garder une même efficacité dans la mobilisation des eaux de surface, on soit amené, périodiquement, à construire de nouveaux barrages en souhaitant que l'environnement n'en souffre pas.

3 Récupération des Colatures Agricoles

Un essai de simulation à l'horizon 2000 a montré que le volume des demandes en eau représentent 76,2 pourcent des apports bruts et qu'elles ont été satisfaites à 94,6 pourcent. On peut se demander quel score aurait été atteint si l'Algérie avait consommé tout ou partie des quelque 18 pourcent d'apports produits par son territoire. Certaines combinaisons d'effets opposés pourraient en résulter comme par exemple la réduction des apports par consommation d'eau, en même temps que la régularisation partielle de ces apports, favorable à une meilleure utilisation de l'eau à l'aval. Cela modifierait de toutes façons le régime hydrologique à la frontière et aurait inévitablement une incidence sur le fonctionnement des aménagements à l'aval. Comme dans tous les cas semblables, la gestion harmonieuse de ces ressources naturelles passe par les accords établis entre les deux pays concernés.

Ce même essai de simulation montre que les pertes par évaporation à la surface des retenues et les pertes par déversement des crues à la mer s'élèvent ensemble à 37,2 pourcent des apports, les 63 pourcent restant constituant 916 Mm³ d'eau mobilisée. Pourtant, il a été possible de fournir aux demandeurs 1 051 Mm³ soit 135 Mm³ de plus que la quantité d'eau mobilisée. Ce supplément a été tiré pour une petite part des réserves non reconstituées dans les nappes et les réservoirs, et pour la plus grande part, 124 Mm³, des eaux de drainage des périmètres irrigués, recyclées dans le réseau hydrographique naturel, et réutilisées plus en aval. Cette récupération de 14 pourcent de la ressource mobilisée, si elle représente en volume un apport hautement apprécié, ne va pas sans de sérieux inconvénients pour le maintien de la qualité de l'eau.

La salinité des eaux de surface de la Mejerdah s'accroît légèrement dans les réservoirs par le jeu de l'évaporation des plans d'eau. En valeurs moyennes interannuelles, elle passe par exemple de 1,9 g l⁻¹ à 2,1 g l⁻¹ dans la retenue de Nebeur. L'effet de l'évaporation sur la salinité dépend bien évidemment de la géométrie du réservoir et du fonctionnement qu'on lui impose; il est faible mais n'est pas négligeable.

En revanche, l'évapotranspiration des parcelles irriguées concentre le sel dans les eaux de drainage. Si l'on considère que, pour ne pas nuire à la fertilité des sols la totalité du sel apporté par l'eau d'irrigation doit être évacuée par les drains, alors le débit de sel dans le cours d'eau est le même en amont de la prise d'eau d'irrigation qu'en aval de la restitution des colatures. Comme le débit liquide est diminué de la quantité évapotranspirée par les cultures, la salinité de l'eau du cours d'eau, en aval du périmètre, est augmentée. C'est ce que confirment les résultats de simulation indiquant en effet que la salinité moyenne de l'eau prélevée et distribuée en aval de Sidi Salem croît progressivement vers l'aval : 1,7...1,9...2,0...2,1 g l⁻¹. Lorsque, en aval de vastes périmètres irrigués les eaux de drainage sont abondantes par rapport au débit restant dans le cours d'eau, leur dilution est faible et on assiste à une grande élévation de la salinité de la ressource restante. On l'observe entre les "anciens" et les "nouveaux" périmètres irrigués de la Basse Vallée.

Dans les conditions retenues pour simuler le fonctionnement du système, un tiers seulement des apports naturels de la Mejerdah atteindrait encore l'embouchure du fleuve mais il contiendrait 80 pourcent du sel qui, naturellement s'y écoule. La salinité de ces eaux rejoignant la mer est alors, en moyenne, multipliée par 2,4.

4 Modification du Régime d'Alimentation du Lac Ichkeul

L'impact probablement le plus important que peut avoir ce grand aménagement sur l'environnement ne se situe pas dans le bassin de la Mejerdah mais dans celui de l'Ichkeul.

Situé au niveau de la mer, le Lac Ichkeul communique avec le Lac de Bizerte lui-même ouvert sur la Méditerranée par le célèbre goulet de Bizerte. Le Lac Ichkeul, alimenté en eau douce par plusieurs oueds dont le Sejnane et le Joumine forme, au contact du milieu marin un écosystème aquatique particulier au voisinage duquel de très nombreux oiseaux migrateurs viennent hiverner, notamment les oies cendrées, foulques et canards. C'est un parc national.

La construction de deux barrages réservoirs sur le Joumine et le Sejnane, et la dérivation de leurs eaux, ont pour évidente conséquence la réduction de l'alimentation en eau douce de ce lac et une modification de son équilibre physique, chimique et biologique. Cela n'a pas échappé aux Autorités tunisiennes qui ont fait procéder à des études nombreuses et approfondies. L'hydrologue que je suis laisse aux spécialistes qui se sont penchés sur la question, le soin de décrire l'impact de ces ouvrages sur l'environnement du lac Ichkeul et les moyens envisagés préconisés à mettre en place pour sauvegarder le milieu. Ce que je peux dire est que le bassin versant de l'Ichkeul s'étend sur 2 224 km² alors que les deux barrages ne contrôlent que 773 km² soit 35 pourcent de la superficie totale. Les barrages réduisent donc l'alimentation en eau douce du Lac Ichkeul mais ne la suppriment pas. La simulation du fonctionnement des deux réservoirs dans le contexte de l'aménagement des eaux du nord permet de comparer mois par mois, sur un laps de temps de 34 années consécutives, les débits effectivement déversés par les barrages aux débits naturels qui auraient coulé dans ces biefs si les ouvrages n'existaient pas. Des 145 Mm³ d'apports annuels moyens au barrage de Joumine 33,6 Mm³ seront rendus au cours d'eau, tandis que l'oued Sejnane ne conservera que 2,1 Mm³ des 104 Mm³ que représentent ses apports annuels moyens au barrage. Au total, les deux barrages feront perdre au Lac Ichkeul peut-être 1/3 de ses apports en eau douce. En outre, les déversements des barrages n'ont pas lieu chaque année mais 4 années sur 10 à Joumine et 2 années sur 10 à Sejnane. Ils se produisent seulement lorsque de grandes crues ont pu rapidement remplir les retenues. Cela se produit exclusivement entre décembre et mai, plus fréquemment en février-mars à Joumine et en mars à Sejnane.

Malgré la rareté de ces déversements, ils peuvent présenter des débits très élevés, d'autant plus proches de ceux des crues naturelles que celles-ci sont exceptionnellement fortes.

En même temps que le régime hydrologique de ces oueds est modifié par le fonctionnement des retenues, les eaux stockées s'y décantent et on estime à 1,9 Mm³ le volume moyen des sédiments qui s'y déposent chaque année. Dans la mesure où les eaux clarifiées déversées, ne reconstitueront que partiellement leur charge solide dans le cours inférieur des oueds, le Lac Ichkeul sera également privé d'une partie des matières en suspension qui, apportées par les eaux douces de surface, s'y déversent naturellement chaque année.

5 Conclusion

Les utilisations de l'eau sont innombrables et naturellement concurrentielles lorsque le volume total des besoins atteint l'ordre de grandeur de celui de la ressource disponible. De

tous temps et sous toutes les latitudes se sont alors établis des droits d'eau coutumiers, traditionnels, qui font désormais l'objet de législation nationales et internationales.

Mais l'usage de l'eau n'est pas uniquement réservé à sa consommation. L'hydro-électricité par exemple ne consomme pas d'eau, elle modifie seulement le régime de l'écoulement, souvent en le régularisant, ce dont bénéficie généralement les utilisateurs placés plus en aval. L'irrigation consomme beaucoup d'eau, mais pas toute l'eau qu'elle utilise, puisque les réseaux de drainage en restituent une partie dont la qualité est certes bien dégradée : l'eau ainsi récupérée dans l'aménagement du nord tunisien représente la moitié des apports qui proviennent du territoire algérien, ou encore la moitié des apports des oueds Joumine et Sejnane réunis.

La gestion coordonnée des ressources en eau régionales est indispensable. Elle vise à répartir équitablement leur utilisation selon la priorité et le volume des besoins à satisfaire, et la qualité requise de la fourniture. La ressource, d'une part, fait l'objet d'une évaluation exhaustive et objective. Son état naturel aux points de prélèvement et de stockage est alors tenu pour stable, non évolutif dans le temps. Les besoins, d'autre part, font l'objet aux points de distribution d'un inventaire qui évolue dans le temps et que l'on cerne à l'aide de critères d'ordre socio-économiques. Les moyens à mettre en oeuvre pour les satisfaire à plusieurs horizons en mobilisant la ressource sont définis dans les Projets d'Aménagements.

La simulation du fonctionnement des systèmes d'eau aménagés ou en projet d'aménagement est un des moyens les plus sûrs de tester le degré de coordination de la gestion des eaux, en confrontant la ressource aux besoins exprimés à différentes étapes de l'avenir. En soumettant le fonctionnement du système à des consignes d'exploitation destinées à répondre aux impératifs techniques, économiques, de qualité de l'eau distribuée, de sécurité, de protection des sites, etc., la simulation apporte sur les réactions du système des éléments de connaissance qui peuvent aider efficacement à prendre les décisions appropriées en matière d'aménagement et de mode de gestion, dans le respect de toutes les contraintes y compris celles de la protection de l'environnement.

PAPER 9

SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF LARGE WATER PROJECTS AND THEIR COUNTERMEASURES IN JAPAN

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*Kuniyoshi Takeuchi*¹¹

1 Introduction

The term "river water projects" means works executed on a river in order to increase public benefits and to eliminate or diminish public damage caused by the river. The relation between mankind and rivers changes with the period and regional characteristics. In Japan there has been a long battle with floods and droughts, and a long history of repeated disasters has given birth to numerous river projects.

Due to the implementation and promotion of large river water projects, particularly after the war, living standards and the nation's economic status have risen rapidly. This represents the principal socio-economic impact of large river water projects in Japan.

Recently, however, this rapid economic growth together with the expansion of cities has brought about other problems. With the progress of urbanization, the improvement of urban river reaches was undertaken by introducing comprehensive flood control and other countermeasures associated with urbanization. At the same time signs of environmental problems appeared in rivers, lakes and reservoirs. Various budgetary provisions and technical or engineering solutions have been introduced to alleviate these problems.

2 The Hydrological Regime in Japan

Due to topographical, climatic and social conditions, rivers in Japan are subject to frequent floods and these greatly influence the characteristics of river projects. (Kinosita et al., 1986). Climatic conditions in Japan may be summarized as follows:

- (a) Japan is subject to monsoon air circulation. Monsoon climates are usually described as having wet periods in summer and dry periods in winter. However, due to the influence of maritime air masses, there is no clearly defined dry season although seasonal fluctuations of precipitation depend upon the monsoon wind system.

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- (b) The annual precipitation is among the highest in the world, and is much greater than the annual potential evapotranspiration.
- (c) Heavy rainfall of short duration occurs, due to tropical cyclones, frontal activities and/or thunderstorms.

The morphological characteristics influencing the hydrological regime are as follows:

- (a) Japan is composed of high mountains with steep slopes and relatively small flatlands at the base of the mountains.
- (b) The mountain masses are generally unstable due to the effects of orogenic movement characterized by seismic and volcanic activities.
- (c) The flatlands are mainly alluvial plains formed by floods and they are still vulnerable to flooding.
- (d) Catchment areas are generally much smaller than those found on continents because of the relatively short distance from the water divide to the sea shore

The combination of these climatic and morphological conditions, associated with human activities affecting the natural environment results in a distinct hydrological regime.

- (a) Favoured by the warm humid climate, rice production is practised widely and its high productivity has met the needs of a large population over many centuries. It can be said that rice cultivation and the dense population are key factors in hydrology-related developments in Japan.
- (b) In warm humid climates rice cultivation is the best form of land use in alluvial flood plains, and over the years has led to a high concentration of population and properties on these lands in spite of their vulnerability to inundation. Therefore, in order to ensure a stable crop, and the safety of lives and property, flood protection measures are of primary concern in Japan.
- (c) Big floods of relatively short duration frequently occur due to topographical and hydrometeorological conditions, involving serious damage in highly developed flood plains. Their hydrographs show sharp rising limbs and quick recessions even in the lower reaches. They must be observed, analysed and predicted on an hourly basis or less.
- (d) Mountain masses formed by orogenic movement have steep slopes and are composed of relatively fragile formations such as lava, unconsolidated volcanic ejecta, fractured zones, tertiary structures vulnerable to landslides, etc.. In addition heavy rainfall specific to warm humid climates causes landslides, hillside collapses, and mud and debris flows in mountain areas, which can result in serious loss of life and property and bring about an aggradation of the river bed in the lower reaches.
- (e) The global phenomenon of rapid growth of population concentration in urban areas has not spared Japan. Most major cities are located on alluvial flood plains. The expansion of urbanization to flood-risk areas is accompanied by serious flood problems.

- (f) In most rice-farming areas, traditional rules for the utilization of river water have been established. With the expansion of irrigation paddy field development has often progressed to a point where almost the whole of the river low flow is required for irrigation purposes. In such cases in order to meet the growing demand for city and industrial water, it is necessary to improve and regulate the water resources with large-scale water projects involving the construction of reservoirs, canals, etc..

3 Development of Large Water Projects and their Impact on the Socio-Economic Environment

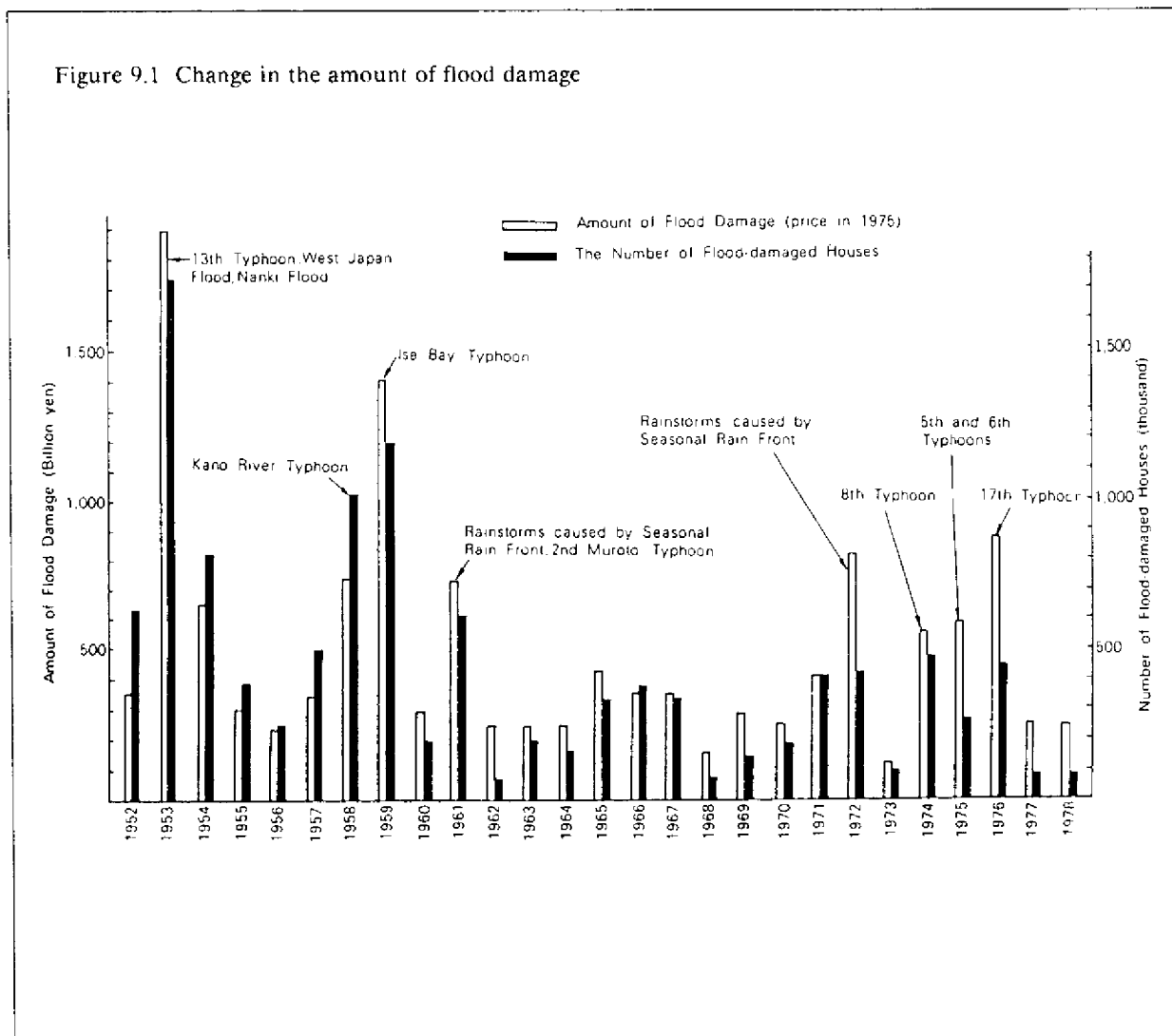
The present River Act was enacted in 1964 in concert with the development of industries and the increased utilization of river water for the purpose of consistent flood control and water utilization.

In accordance with the River Act, the rivers are classified as follows. River basins that are of major importance from the standpoint of land conservation and national economy are designated as class A basins. Rivers in class A basins are designated as class A rivers. The administration of such rivers are under the responsibility of the Ministry of Construction. Class B rivers and those to which the River Act applies *mutatis mutandis*, are managed by the prefectural governors and city town or village authorities.

Large river projects have mainly concerned class A rivers. These projects involve the construction of (1) multipurpose and flood control dams, (2) development of lakes, (3) building of training structures in estuaries and (4) multipurpose projects for efficient flood control, to maintain the normal stream flow and in particular to develop water resources. Multipurpose dams occupy the most important position in river projects. Table 1 shows the number of multipurpose dams built since 1900.

PERIOD							
1900 to 1925	1926 to 1945	1946 to 1955	1956 to 1965	1966 to 1975	1976 to 1985	After 1986	
1	11	24	94	127	237	164	

These large projects have contributed greatly to flood protection and water resources development, favouring Japan's high economic growth and improved standards of living and expanded production. Changes in the extent of flood damage and water demand are indicated in Figures 1 and 2.

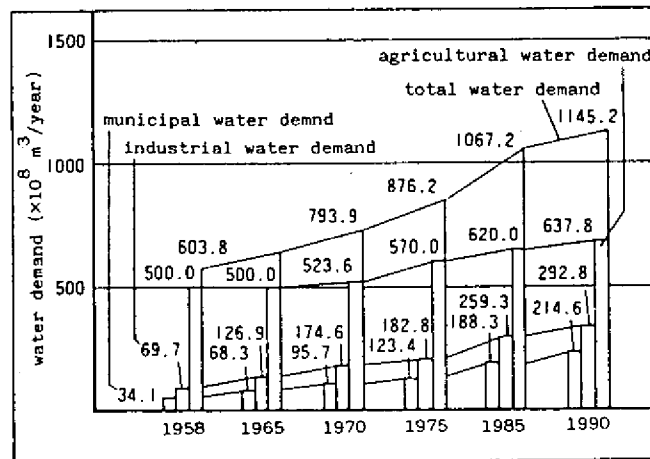


It is worth noting that the large water projects have also had considerable socio-economic impacts and benefits. The progress in research on runoff modelling and forecasting facilitates each stage of planning, design and operation of the river projects and is to the credit of the many hydrologists and river engineers working in Japan.

Moreover, in recent years, river projects have been planned and implemented in a more comprehensive or integrated manner in order to ensure high economic growth and to deal with rapid urbanization and the needs of a cultured and quality-oriented mature society.

On the other hand, in recent years in addition to the social and economic impacts of the river projects, environmental impacts have become evident. Though their origins are essentially social, economical and hydrological with the increased degree of land utilization,

Figure 9.2 Rate of increase of water demand. (National Land Agency, 1978).



they can be partly attributed to the decrease in the number of good sites for dams. As multipurpose dams occupy the most important position among large river projects, the following social and environmental impacts relate to dam and reservoir construction.

4. Social Impacts and their Countermeasures

Different from other public projects, dam projects greatly affect the residents whose houses and surroundings may be submerged by the reservoir and it is indispensable to take suitable measures to relieve the hardships incurred by the population concerned.

The livelihood of residents concerned must be maintained and their welfare enhanced by reconstructing the living environment and basis of production in reservoir areas in accordance with the Act on Special Measures for the Reservoir Areas Development. This is in addition to compensation offered by the dam owner. 62 dams had been subjected to the provisions of this law by the end of fiscal year 1985. Designated projects are government subsidized, and a proportionately higher subsidy is awarded for large dams involving extensive submerged areas. These measures also apply to large-scale lake development projects, and one such project is currently affected by these provisions.

The costs of executing reconstruction projects are sometimes partially borne by the beneficiaries located downstream. In addition to the compensation by dam owners "Fund for Reservoir Areas Development" was established for certain areas funded by the Government, prefectorial authorities and city councils concerned. The livelihood of residents whose houses have been submerged has in certain cases been provided for with this fund.

5. Environmental Impacts and their Countermeasures

Dams are frequently accompanied by great social changes resulting from submergence of existing villages and splitting up of communities as stated above. At the same time some physical and environmental problems occur at certain dams, such as sedimentation and long-term turbidity in the reservoir due to floods, eutrophication as a result of human activities around the reservoirs, discharge of cold water downstream and landslides around reservoirs, as well as environmental degradation.

To cope with physical and environmental problems associated with dams, various projects as well as reservoir conservation projects have been undertaken in Japan. In the following section problems associated with sedimentation, long-term turbidity and eutrophication and possible countermeasures are examined.

5.1 Dam construction and Environmental Impact Assessment

The "desirable impacts" of dams are flood control, water utilization, water-recreation and water resources development which are the original objectives. They also produce "undesirable impacts" to the nearby natural and social environments. These impacts can be divided into the short-term ones, occurring at the time of the construction of the dam, and the long-term ones resulting from the creation and operation of the reservoirs. By means of environmental impact assessments, the "undesirable impacts" may be forecast and relief measures taken where necessary.

In "Technical Guides for the Environmental Assessment of the Projects Controlled by the Ministry of Construction, Dam Projects, 1978", methods of environmental impact assessment are prescribed relating to health, human and natural environment. According to these Guides, the environmental impact assessment must be made in the sequence indicated in Figure 3 (Ministry of Construction, 1984).

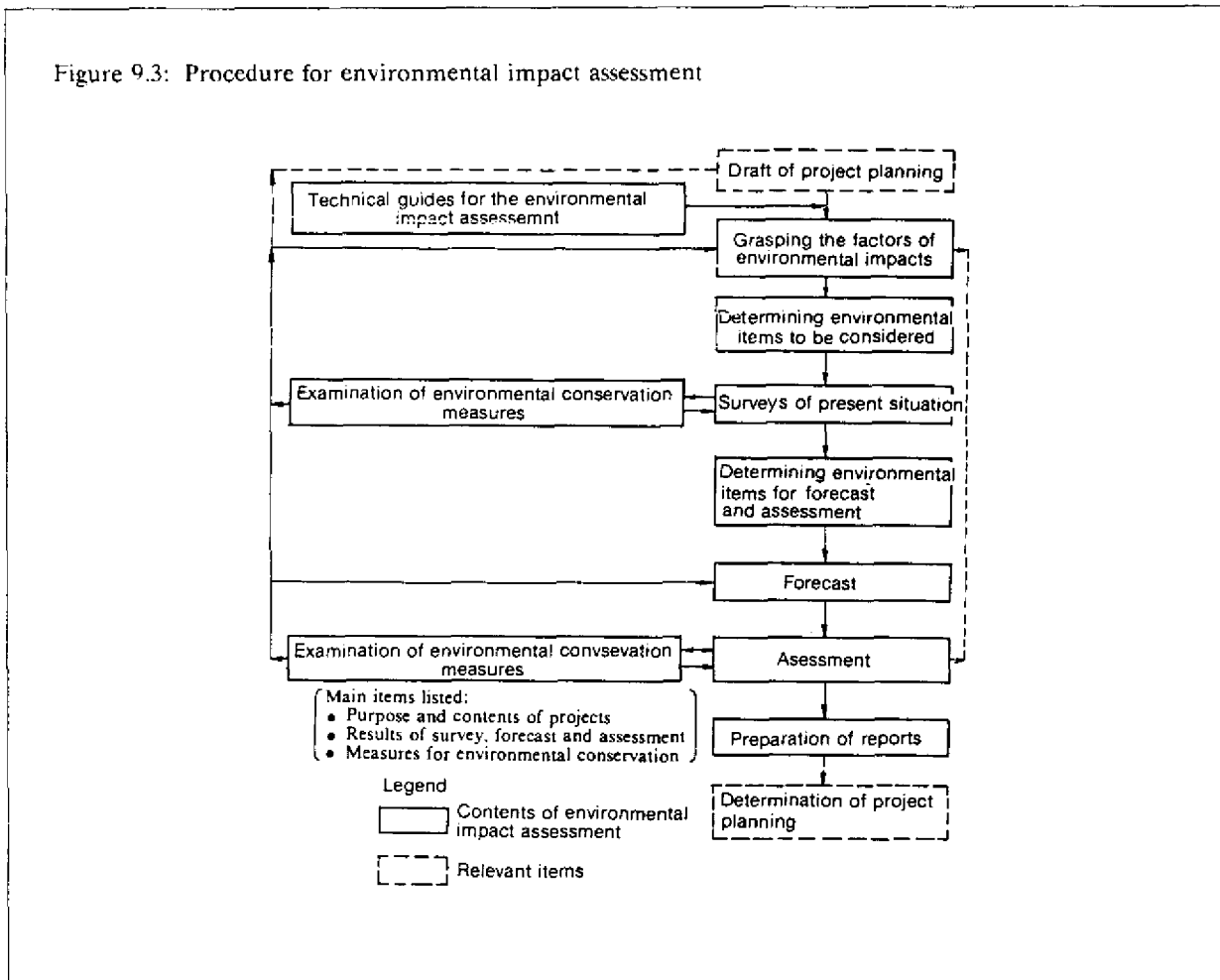
A list of environmental impact factors and basic items to be considered and assessed for each environmental situation together with survey methods are prescribed in the Guides. The findings of the environmental impact assessment are submitted for approval to the local governments concerned at the time of formulation of the project master plan.

5.2 Reservoir Sedimentation and Countermeasures

On account of geographical and meteorological conditions, Japan is exposed to floods, landslides and mud and debris flows in periods of heavy rainfall so that reservoirs tend to store the transported sediment. Figure 4 shows the relation between sediment transport rates and watershed area for some selected reservoirs. The distribution and mechanical processes involved have been investigated from the hydraulic and hydrological aspects.

In order to reduce the sediment load from the mountainous region entering the reservoirs a land conservation programme (called Sabo works) has been developed in the upper watersheds in mountainous regions producing large amounts of debris. There are several types of such works. The first include the treatment of landslide sites to prevent the production of debris. The second consists of Sabo dams placed at appropriate sites on the rivers. Where the banks and the river bed are severely eroded over a long distance, a cascade of Sabo or step dams are built. The third facet concerns the alluvial fans formed at

Figure 9.3: Procedure for environmental impact assessment

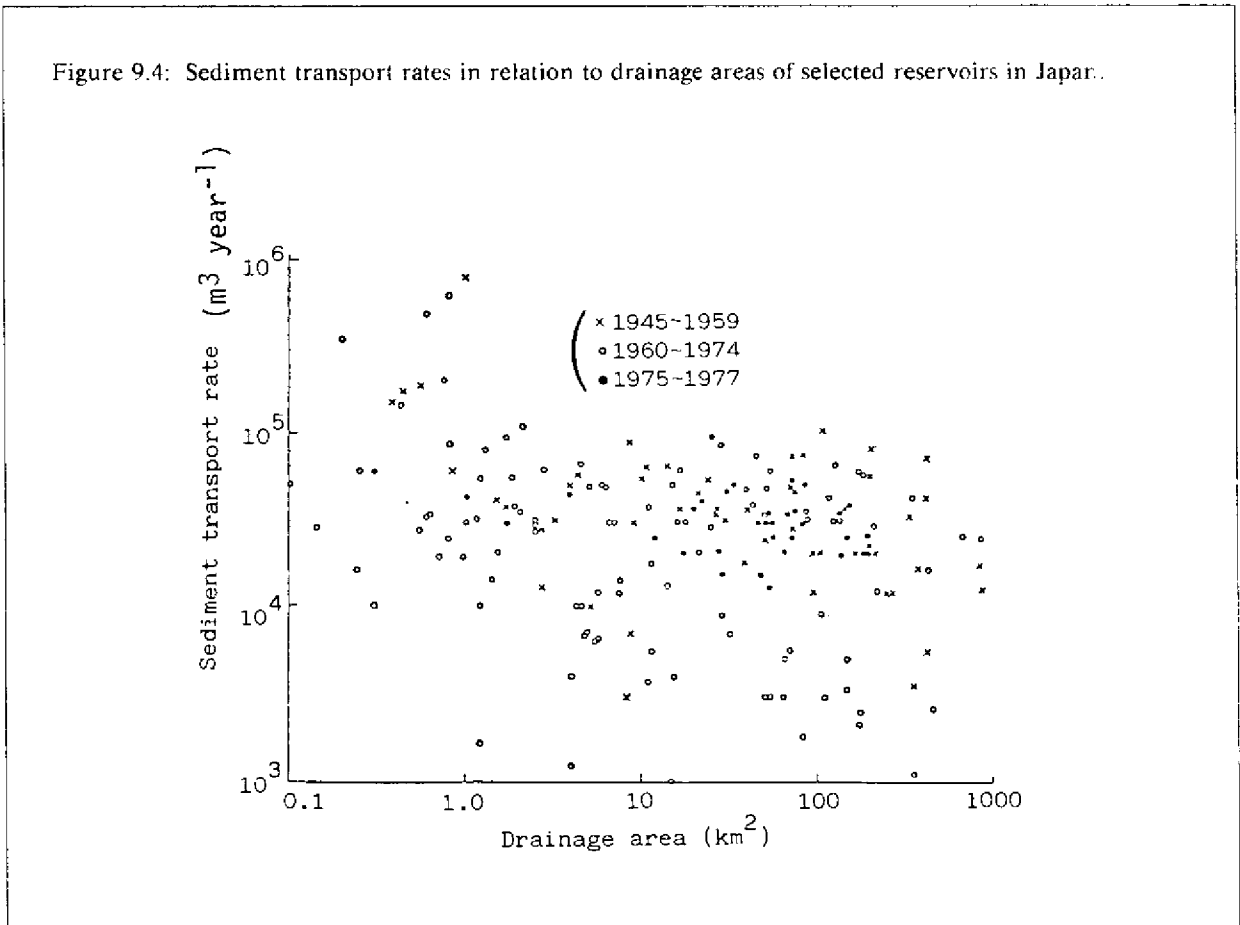


valley outfalls where the water course is often unstable and considerable amounts of sediment in the form of sand and stone are produced. The river course is stabilized by training works in the channel and low Sabo dams.

Recently, in addition to Sabo works, weirs have been built in the backwater upstream of the reservoirs and direct excavation of accumulated sediment in the vicinity of the reservoir sediment flushing gate has been undertaken.

5.3 Long-term Turbidity and Related Countermeasures

When river water and its suspended load enter the reservoir and remains there, long-term turbidity phenomena occur. Figure 5 shows the turbid water phenomena which occurred at Kazaya reservoir. This reservoir has a 553 km² catchment area and a total storage capacity of 130 Mm³. Digital models have been developed to analyze the turbidity distribution in reservoirs both in time and in space. The effects of dam operation on long-term turbidity have been studied with the help of these models and operational hydrology. In this way it has been shown that the long-term turbidity problems can be partly solved by installing selective intake structures (including surface intakes) as required.



5.4 Eutrophication of Reservoirs and Related Countermeasures

The assessment of water quality in reservoirs is defined by the Basic Act for Prevention of Public Nuisance which prescribes observations of pH, BOD (COD), SS, DO and the coliform group.

Table 2 shows the percentage of water bodies which meet the environmental quality standard. Reservoirs maintain good water quality compared to lakes and rivers but in certain reservoirs the rapid growth of organisms is an obstacle to water use.

In particular, when a large pollution load is produced in the catchment, the accumulation of nutrient nitrogen salts, phosphorus, etc. leads to reduced transparency, an increase of micro-organisms and alteration of species, as well as eutrophication. This results in the proliferation of water flora. Eutrophication of reservoirs creates difficulties at water treatment plants and gives an unpleasant smell to municipal water, as well as affecting the fisheries industry and spoiling of scenery due to the colouring of the water in reservoirs or lakes.

Figure 9.5: The relation between predicted and observed values of the turbidity of the out-flow water. (The flood occurred at the beginning of July, 1974).

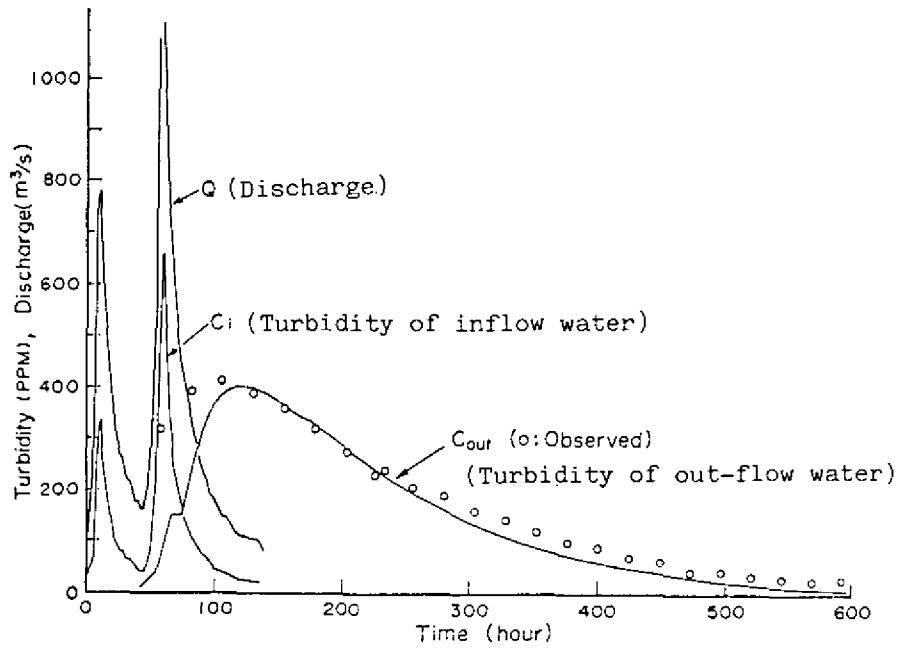


Table 2: Percentage of water bodies which meet the environmental quality standards

Reservoirs	Lakes	Rivers	Sea
81.4	41.8	65.0	78.2

Note: BOD for river, COD for lake and sea and BOD or COD for reservoirs.

Table 3: Methods for improving water quality in reservoirs

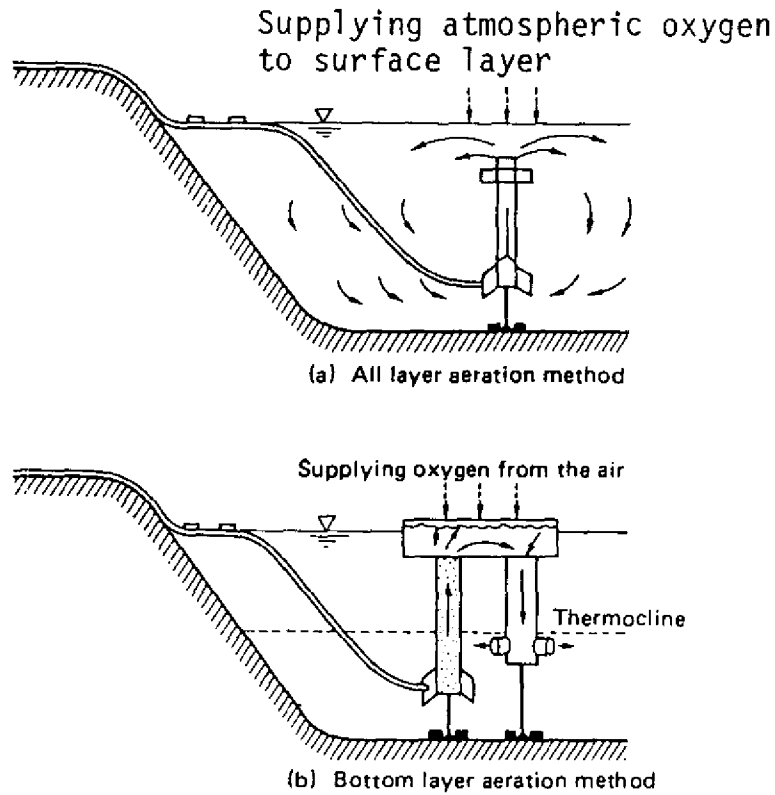
Measures upstream of reservoirs (control of nutrient loads)	Measures for point sources	Chemical coagulation treatment of sewage Reduction or elimination of phosphates in detergents Excavation of bypass channel
	Measures for non-point sources	Restricting fertilizer use Seepage gutters Aluminium oxide filters Removal of phosphorus by pre-reservoir Removal of phosphorus from main inflow Restricting land utilization
Measures in Reservoirs	Removal of nutrient salts in reservoirs	Chemical coagulation in reservoir Dilution and flushing Discharge from deep layer Removal of nutrient salts by removing organisms Drying and removal of sediment at the bottom of reservoir after dewatering Treatment of reservoir bed (lining)
	Emergency measures for eutrophication	Aeration (circulation) Control of aquatic plants by varying water level Physical measures (cutting aquatic plants) Chemical control (use of weed and algae killers) Biological control (treatment by predators)

Various countermeasures have been introduced to deal with eutrophication problems as shown in Table 3. Conservation measures suited to the specific situations of reservoirs are also being taken, especially since 1982, in order to systematically cope with water quality problems. They consist mainly of countermeasures to deal with eutrophication by aeration (circulation) as shown in Figure 6.

Water quality conservation pilot experiments are presently being carried out at four dams by the Ministry of Construction and the Water Resources Development Public Corporation. No final conclusions have yet been drawn, but an outline of the results obtained so far at Muroo Dam is given below (Ministry of Construction, 1985).

Muroo dam, completed in 1974, is a flood control dam which also provides municipal water. The reservoir characteristics are shown in Table 4. The T-N and T-P contents of the water are high at 1.95 mg l⁻¹ and 0.154 mg l⁻¹ respectively, water-bloom appearing from the beginning of impoundment followed sometime later by offensive smells released by municipal water drawn from this reservoir. In addition to selective intakes, activated carbon has been introduced together with ozone treatment when necessary.

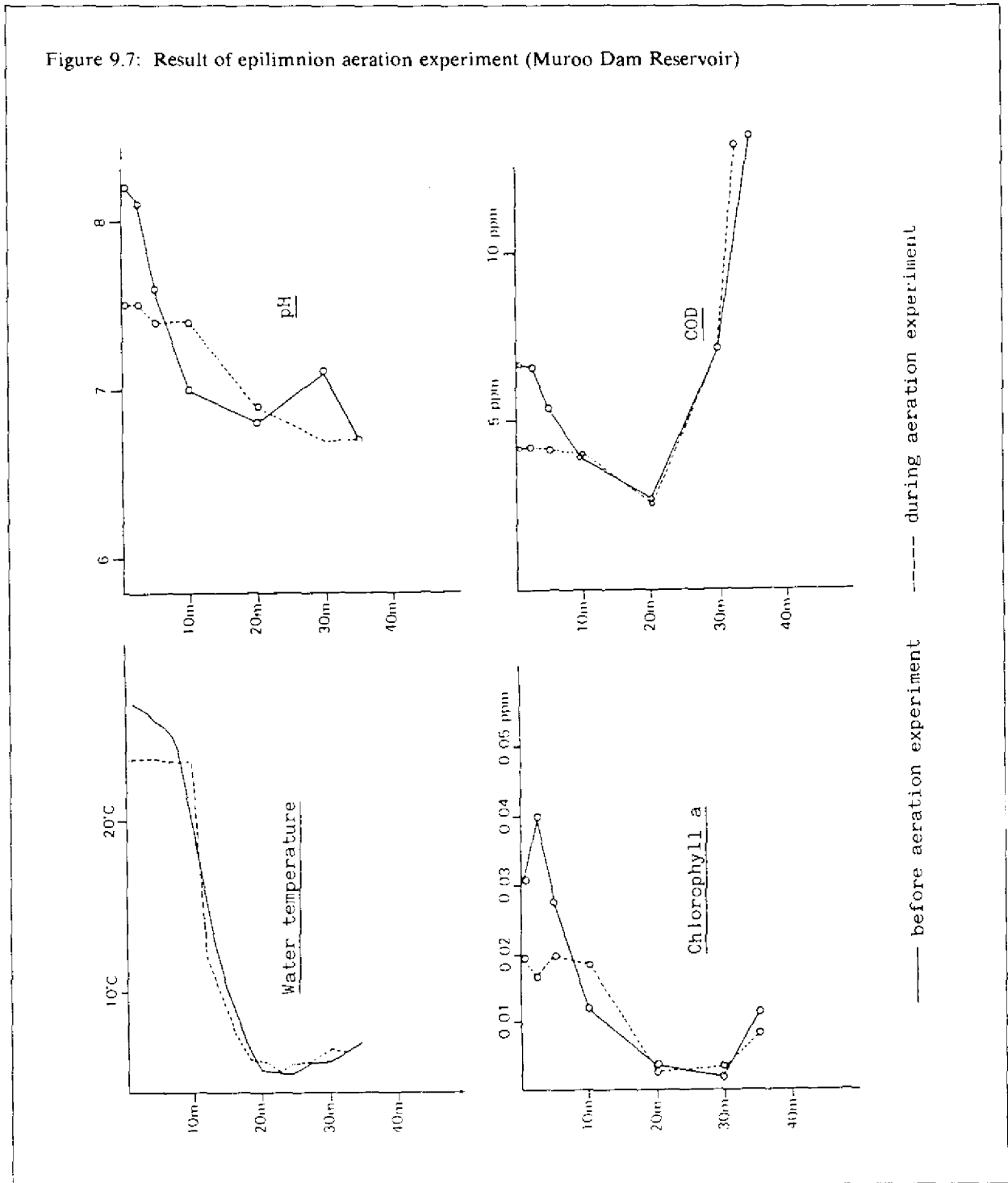
Figure 9.6: Aeration method for Muroo reservoir conservation



A river basin sewer line project was started in the area upstream of the dam in 1980 which is due to be completed by 1990. The dam administration agency, in order to control the abnormal proliferation of algae, thought to be the cause of the offensive smell, has been performing epilimnion aeration with an intermittent air lift pump since 1980.

Up to the present, as shown in Figure 7, the aeration and circulation of epilimnion water has tended to reduce the temperature as well as the amount of chlorophyll but it cannot be said that proliferation of harmful algae in the Muroo Dam reservoir has been brought under control. However, of all the Japanese reservoirs this is the one which has the highest level of eutrophication.

Every effort is being made by research workers and engineers to develop simulation models and more effective countermeasures.



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River Bureau, Ministry of Construction: Multipurpose Dams in Japan, 1984, pp. 74-79.

Table 4: Reservoir conditions of Muroo Dam

Reservoir Conditions

Reservoirs Specifications				Basin Conditions					
Effective Storage Capacity (Mm ³)	Surface Area (km ²)	Av. Depth (m)	Retention Time (days)	Catchment			Population	Cattle (head)	Swine (head)
				Area (km ²)	Forest	Farm-land			
14.3	1.05	16.1	40	136	65%	12%	34 000	1 270	220

Inflow Water Quality

Reservoir Water Quality

COD	4.2 mg l ⁻¹	48mg l ⁻¹
T-N	1.949	2.269
T-P	0.154	0.082

River Bureau, Ministry of Construction: Development of Water Resources and Control of Water Quality, 1985, pp. 6-9.

T.Kinosita, K. Takeuchi, K. Musiake and S. Ikebuchi: Hydrology of Warm Humid Islands, Comparative Hydrology (IHP Project 4.9), 1986, pp. 1-4.

PAPER 10

IMPACT OF PEAK LOAD OPERATION OF RUN-OF-THE-RIVER POWER PLANTS

Dr. O. Starosolszky¹²

1. The purpose and problems of peak load operation

Hydropower is still and will remain a major economical source of energy production. In a traditional mixed power generation system hydropower stations may be used for peak energy generation due to their capabilities of flexible operation. Hydraul-pump storage plants are economical supplements for thermal stations, including nuclear power stations, to carry peak load. In certain countries, in particular in flatlands, run-of-the-river power plants are also used for peak load generation.

Peak load operation normally causes regular variations of flow according to the energy demand (Laczko-Starosolszky, 1963). Since energy demand is varying within the day, and is characterized normally by one or two peaks, the flow regime of the river becomes unsteady and is characterized also by one or two peaks corresponding to the energy production (Figure 1). This peak-load type of operation can drastically influence the normal hydrological regime. During the design of hydropower schemes the effect of the planned peak load operation should be studied and necessary restrictions should be formulated. After commissioning the power stations further field investigations may be necessary to follow the responses to the variable flow regime and their interaction with the environment.

The effect of peak load operation of hydropower stations (Starosolszky, 1974) can be a major preoccupation for the environmental impact studies institutionalized in several countries.

Since peak energy has is generally of much higher value than base energy, the permissible peak operation capability of the station can be mandatory in the feasibility study or in cost-benefit analysis of the hydropower scheme investment (Laczko and Starosolszky, 1963). The installed capacity of a run-of-the-river power station also depends on whether the station can be operated to generate peak energy in the periods when the daily mean discharge of the river is less than the discharge capacity of the hydropower station.

The problems related to peak-load operation may be classified in three main categories

- (a) How much continuous flow is necessary in the riverbed (e.g. "sanitary" flow).

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- (b) What range of level variation and what rate of change of level can be permitted in the river channel considering different aspects.
- (c) Which other factors should be considered in order to legally restrict peak-load operation.

Item (a) affects the available water volume for peak energy generation. Item (b) influences the time base of the peak-load operation, the schedule of the operation, including the initial and final periods, the permissible rates of change. Item (c) may influence the economic feasibility of the investment, and in particular the installed power capacity.

2. Minimum flow in the riverbed

Minimum discharge depends, amongst other factors, on whether water level is sensitive to discharge and whether downstream water level regulation (e.g. by barrages or weirs) is feasible. Aquatic life reacts favourably to steady water levels. Bank vegetation is more sensitive to groundwater level variations than to the river level itself.

The form of the stage-discharge relation may influence the rate of the reduction of the flow. Due to the unsteady flow the minimum water level is normally never reduced to that which corresponds to the minimum artificial discharge. Thus, the rating curve cannot be extrapolated mechanically to determine the minimum daily water levels resulting from the reduction of flow. Nor can the daily maximum stage be calculated on the basis of the maximum flow corresponding to peak energy production. Such a calculation could lead to overestimating the influence of the daily variation of discharge and produce an unrealistic negative assessment of peak load operation.

Since unsteady flow calculations (Ratky, 1979) can easily be performed by computers, daily variations of discharges and water levels corresponding to different minimum flows should be simulated and variations of water levels estimated in this way. At the preliminary design stage, several approximations are acceptable (e.g. rapid rise and fall of flow).

3. Effects of peak-load generation

Besides the water level, the velocity of flow is an important parameter for estimating the influence of peak-load operation. Velocity is of importance for navigation and bank protection. If the maximum flow is calculated as a surge wave (Starosolszky, 1965) and its velocity is misinterpreted as representing the velocity of the water particles, it could not be tolerated either by navigation or by the channel. Of course, it is the mean flow velocity which corresponds to the equation of continuity, and it can simply be expressed as the ratio of the maximum discharge to the minimum cross-sectional area at the beginning of the peak.

The increase of velocity can be reduced to some extent by introducing stepwise change of flow (and output, consequently) rather than by increasing the minimum (continuous) flow.

Nature is more sensitive to the rates of change (e.g. accelerations), than to the absolute values of changes. This is the reason why item (b) above should be studied in detail.

The rise and fall of water levels and velocities depend primarily on the start and finish of peak operation. In this respect the sudden (emergency stop) closure of the power station (which is consecutive to an incident and does not result from normal operation) should not

be confused with daily peak-load operation according to regular schedules. The schedule is planned according to the permissible rate of change of discharge. In certain cases the limits of the artificial flood wave cycle can be 20-30 minutes, which fundamentally affects the rate of rise or fall of the water stage and of the velocity.

Another misconception is that the rate of change of flow at the power station can automatically be transferred to downstream or upstream river reaches, irrespective of the distance from the station. The attenuation of artificial flood waves is fairly rapid and strong, normally following an exponential curve, the attenuation being highest in the vicinity of the power station (Starosolszky, 1965).

Unsteady flow calculations (Ratky, 1979) can eliminate such misconceptions and demonstrate that the stronger effects are limited to the vicinity of the power stations. However, it should be recognized that close to the hydraulic structures the phenomena can be of three-dimensional character, e.g. oblique flows and a wave front may occur, and therefore navigation should be duly warned.

Peak operation, as regards its influence on the water regime, follows the random process of the natural flow regime, by superimposing its effect. It can thus be studied with the assistance of duration curves widely used in hydropower engineering for characterizing head, discharge and power output variation with time (Starosolszky, 1977, 1981).

Duration curves may be used to represent the periods when peak energy can be generated with a given installed capacity, the periods when certain daily water level variations may be expected, the length of the periods when water level and velocity variations may exceed certain values. Such curves can be constructed on the basis of assumptions made concerning the lengths of the daily peak periods and the shape of the output time-series.

The regular daily variations of flow, velocity and water levels involve various processes, some of which are partially irreversible. A typical example is the suspended sediment regime. The settling and scour processes are irreversible, because of hysteresis at the critical velocity. A certain fraction of the sediment may be deposited during the minimum flow period and not be scoured even during the maximum flow period. The process itself is evident, particularly in certain parts of the cross-sections, but is not often investigated. Another typical example is the ice regime. Ice cover stability may be endangered either by the rise of water levels or the increased velocity. The strengthening of ice cover along the banks of the upstream pool can certainly be expected due to the regular daily cracking and overlapping of the ice cover. Ice jam formation may also occur in the downstream reach if a peak wave breaks the ice cover in the vicinity of the power station and ice floes start to move and consolidate the downstream ice sheet.

4. Restrictions

Peak-load operation can certainly be beneficial for power generation but can negatively influence other waterusers or the environment. For this reason, legal restrictions should be imposed upon the power utility if the environmental impact assessment demonstrates the need. Major restrictions can concern:

- (a) The minimum flow to be continuously released either in terms of absolute value or as a percentage of the incoming flow.

- (b) The period of the permissible peak operation (e.g. restrictions during periods of ice formation).
- (c) The maximum rate of change of discharge due to peak operation.

Besides these restrictions the power utility may be made financially liable for certain repair and maintenance works (e.g. bankslides, dredging, etc.) as compensation for damage due to peak-load operation.

5. Conclusion

Detailed laboratory and field studies (Laczko-Starosolszky, 1963; Starosolszky, 1965, 1981) on Hungarian rivers related to existing and planned hydropower stations operated for peak-power generation clarified several phenomena and put an end to certain misconceptions. These were useful for estimating the influence of peak-load regime correctly and to ensure proper design of peak operation systems.

Peak-load operation of hydropower stations in low water period may increase their economic benefit provided that proper operational limitations are defined. If peak energy generation is a major concern, hydropower can contribute to this demand but careful investigations are necessary at the individual sites to prevent harmful environmental effects.

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Figure 10.1: Typical stage hydrograph for continuous peak operation in low water period

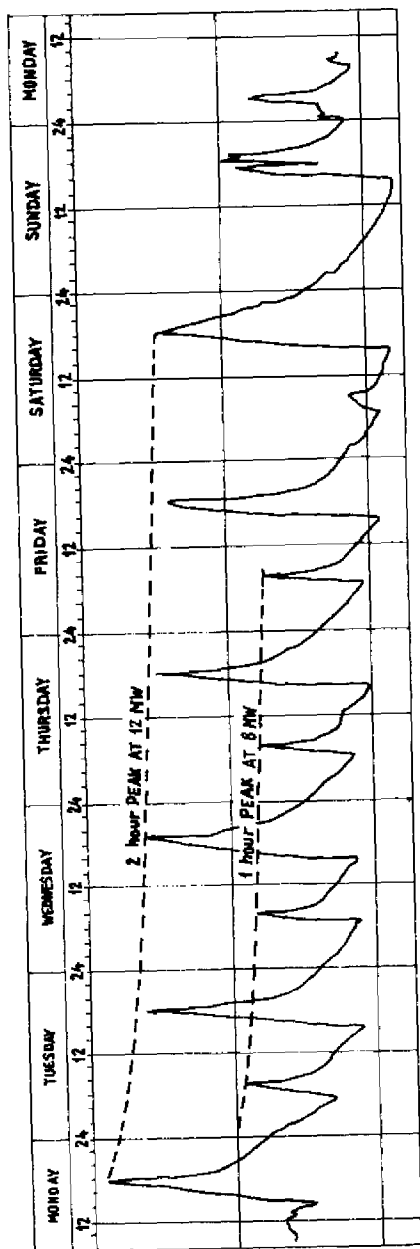
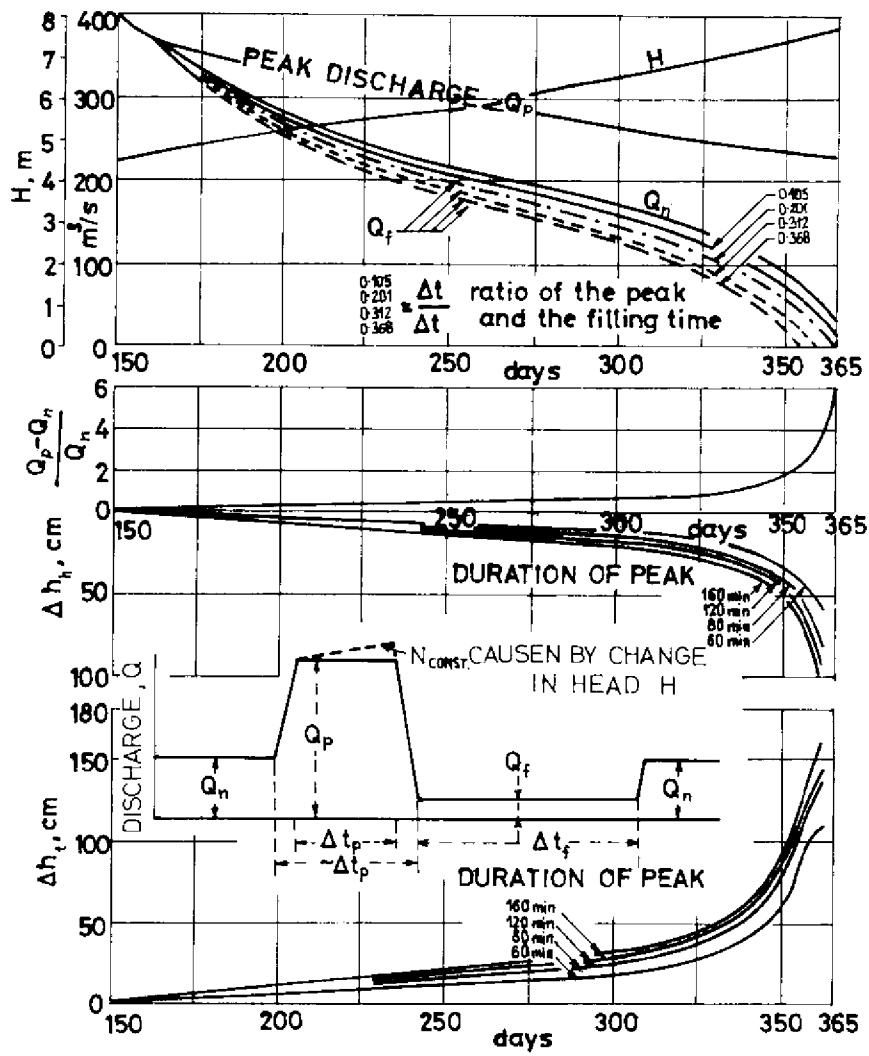


Figure 10.2: Duration curves of change of head, relative increase in flow, headwater drop and tailwater rise for different peak and refilling periods for a given maximum output



PAPER 11

COMPARISON BETWEEN THE DIFFERENTIAL IMPACT OF DAMS ON TWO LARGE RIVER BASINS IN ARGENTINA

A.A. Bonetto, H.P. Castello & I.R. Wais

1. Introduction

The relative scarcity of the continental water resources of Argentina and their particular distribution have determined varied strategies related to their regulation and management. In the North-East of the country the large rivers of Del Plata system and its affluents represent about 85 percent of the total resources, whereas 10 percent originate in the rivers of the Patagonian Region in the extreme South of the country where lakes and river catchments receive rainwater and snow and glacier melt in the Andes. Downstream, the extended Patagonian plateau *per se* is very arid. The remaining 5 percent originates in an area of variable dryness, located in Central Argentina, characterized by scarce rivers with seasonal flow commonly related to endorheic systems.

Such a situation has led to the formulation of various regulation projects, which correspond to the different regional and general requirements, and which entail varied impacts on the affected ecosystems. The result will be the construction of structures which with more or less success will lead to a positive modification of the environment. Consequently, in order to compare the different criteria and strategies for harnessing the rivers of the country, the most outstanding aspects of the dams already built or projected will be considered, and their positive effects examined. A comparison of the existing and future dams of Parana and Negro rivers will be undertaken here. The first one, shared with Paraguay, Brazil and Bolivia, concerns the most developed river system of Argentina (and South America); the second concerns the largest river system having its origin and outfall in Argentina but with a minor impact on the environment.

In Northeastern Argentina, where water resources are abundant, the general policy is oriented to their massive utilization by means of hydropower schemes. Although they are considered as multipurpose dams, their primary function is energy production, the other supposed benefits being of little significance (flow regulation, lowlands drainage, irrigation, navigation, fisheries, recreation). These dams, however, may cause serious ecological impacts.

2. The Parana Basin and its Regulation Projects

The Parana river is 4 000 km long and its basin has an area of 2 800 000 km² distributed over Brazil, Bolivia, Paraguay and Argentina. Its upper reaches are on the Brazilian Central Plateau and it traverses about 1 700 km of Argentine territory (25^o-34^o S, 56^o-61^o W), most of which consists of a low plain, until it drains to the Del Plata estuary. The maximum

discharge can attain $65\,000\text{ m}^3\text{s}^{-1}$ in summer, due to heavy rains on the Brazilian headwaters. Low water occurs generally in autumn and winter.

According to its main physical and biotic characteristics, the Parana river may be divided into four reaches: *Superior*, as far as Itaipu dam (in the past to Guayra falls); *Upper* or *High*, down to the confluence with the Paraguay river; *Middle*, to a transversal section connecting Carcarana on the right bank with Diamante on the left bank; *Lower*, down to the Del Plata estuary. The Middle and Lower Parana have a wide and complex floodplain that ends in a delta region 320 km long and up to 60 km wide, devoted to soft wood forest exploitation, orchards, dairy and cattle farms. It is paradoxical that though most of Argentina's population and industrial power is established on the banks of Lower Parana and the right bank of the Del Plata estuary, this reach is perhaps the one that has been studied least, specially as regards its limnological and ecological aspects, in spite of its accessibility.

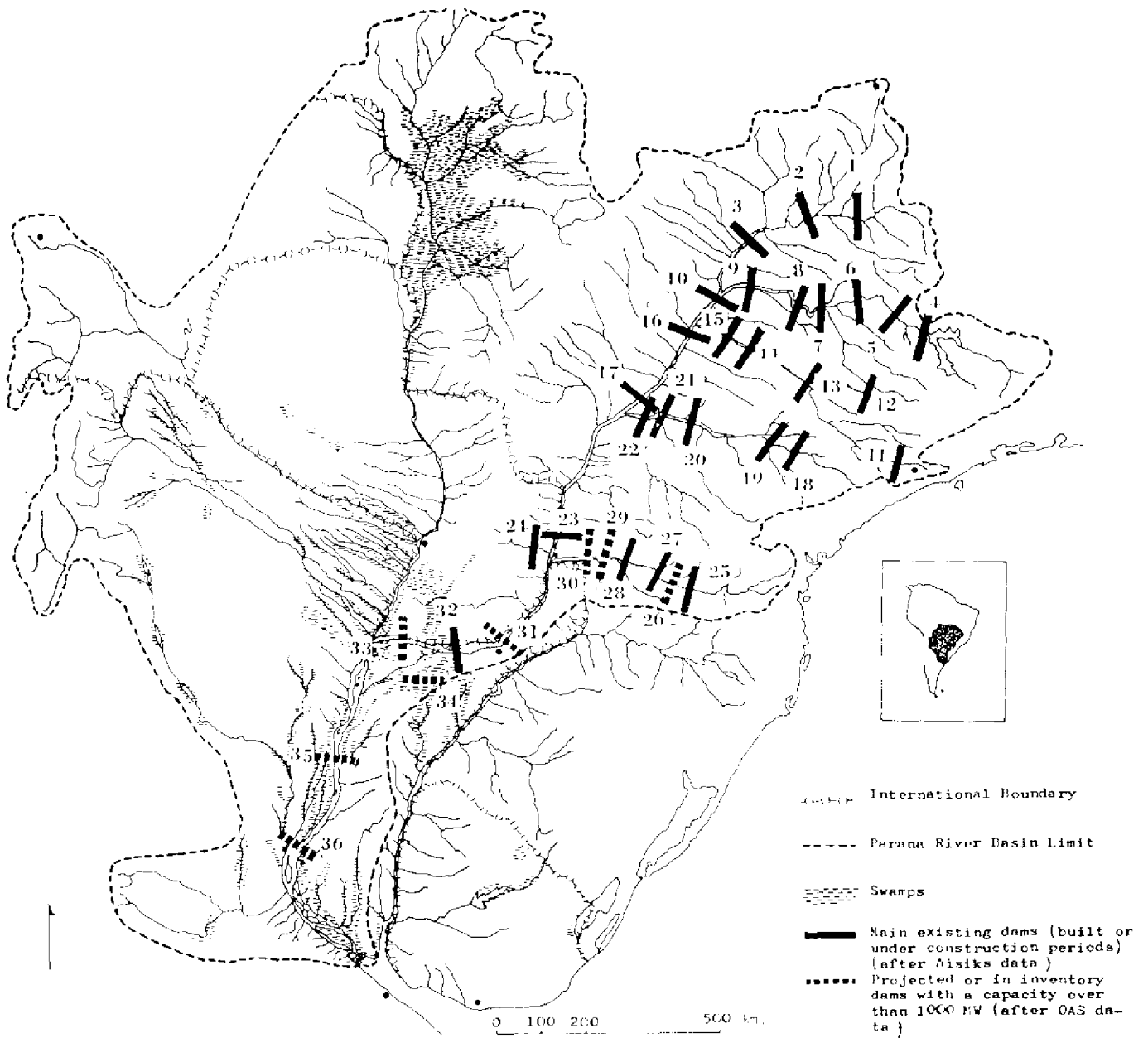
The main tributary of the Parana is the Paraguay river, 2 550 km long, draining an area of $1\,100\,000\text{ km}^2$, with a flow of $4\,550\text{ m}^3\text{s}^{-1}$. Numerous powerful hydroelectric dams have been constructed on the Parana river and its tributaries, while others are planned or are under construction (Figure 1). Consequently, the river system will become totally harnessed, with one man-made lake after the other. The Organization of American States has surveyed a total of 23 hydroelectric dams (four of which are bilateral) of over 1 000 MW capacity each (OAS, 1985). Ten are installed on the main course of the river. Most of the regulation projects on the Superior Parana have been constructed by Brazil (in some cases with Paraguay), while on the Argentine Upper Parana the Yacyreta dam is under construction and the feasibility studies for the Corpus project have recently been finished both in collaboration between Argentina and Paraguay. On the Middle Parana the Machuca Cue and Chapeton dams are projected, while a third dam at Parana-Guazu on the Lower Parana is under consideration.

The Parana river water has a low salinity of the bicarbonate-calcium-magnesium-sodium type, relatively low in calcium. Water quality remains almost unaltered, even though conductivity at the mouth is up to 3 to 4 times above its baseline levels, with increasing chloride, sulphate and sodium concentrations. Important quantities of industrial and domestic sewage are thrown into the Superior and Lower Parana, where South America's highest human concentrations and industrial development are found; however, water pollution only becomes evident in some tributaries and sometimes on the banks of the river, mainly on the right of the Lower Parana. The river's self-depuration capacity is so high, that even though there is no prior treatment of sewage, the waters are oxygenated with a frequent phenomena of oversaturation, having extremely low BOD and COD values (Bonetto, in press). Some eutrophication phenomena may now be observed as cyanophyte algae blooms, specially in periods of low water during spring and summer.

The Parana river in its Superior and Upper reaches presents a typical load of finely-divided suspended solids derived from lateritic soils, giving a reddish colour to the water. It increases rapidly during the flood period, reaching nearly 100 mg l^{-1} . Its influence extends up to the Del Plata estuary and the Atlantic Ocean, contributing to the delta's soil development. The Bermejo river, a tributary of the Lower Paraguay, transports during high water periods over 62 Mm^3 of sediments each year (Soldano, 1947). These specially coarse silts, when transported to the Middle Parana, are mainly deposited on a relatively short reach. Nevertheless, downstream there is a slight but constant increase of transported solids derived from river erosion which can be found up to the Lower Parana (Bonetto, 1976; Bonetto and Orfeo, 1984).

Dams on Two Large River Basins in Argentina

Figure 11.1: Parana River



- Dams: (1) Embarcação; (2) Itumbiara; (3) Sao Simao; (4) Furnas; (5) Estreito; (6) Volta Grande; (7) Porto Colombia; (8) Marimbondo; (9) Agua Vermelha; (10) Il-h Solteira; (11) Cubatao Externa; (12) Jaguari; (13) Barra Bonita; (14) Promissao; (15) Nova Avanadaba; (16) Jupia; (17) Porto Primavera; (18) Jurumiran; (19) Kavanies; (20) Capavara; (21) Taquarucu; (22) Rosana; (23) Itraipu; (24) Acaray I, II y III; (25) Foz do Areia; (26) Segredo; (27) Salto Santiago; (28) Salto Osorio; (29) Capanema; (30) Machadinho; (31) Xoepua; (32) Yacireta; (33) Irati-Itacora; (34) Ihera; (35) Pati (Machuca Cué); (36) Chapteon.

The delta - 17 500 km² - is periodically flooded to a variable extent as a consequence of a delicate equilibrium between the Parana waters, the tides and the Southeastern winds ("Sudestada"). Under certain circumstances, the delta has been completely flooded, as occurred during 1905. According to Soldano (1947), the delta was increasing at that time by 55 to 90 m per year and it was extending also as an underwater delta towards the estuary. Any variation of the sediment load that might occur as a consequence of the construction of dams and its effects on the delta's evolution should be studied. If Corpus, Yacyreta (Upper Parana) and the two Middle Parana dams are built, a substantial reduction of the suspended solids load is to be expected, with a probable negative effect on the delta's dynamics, and a decrease of its surface area. It may also be assumed that erosion phenomena will occur along the coast of Buenos Aires province. The rupture of the equilibrium between the Parana river and Del Plata estuary would affect water quality due to sea-water penetration with possible serious consequences for the city of Buenos Aires and its surrounding densely inhabited areas. All the activities on the delta might be affected to some extent. In relation with suspended solids it is necessary to remember that they also contribute an important load of "sorbed" phosphorous, which according to Pedrozo and Bonetto (Ms) may be estimated at 160 gl⁻¹ at the Paraguay and Parana confluence. Logically, solid retention by dams will reduce the nutrient contribution to the Del Plata estuary and its high biological production with a negative effect on food chains in the estuary and nearby maritime fisheries.

The Parana river has a predominant N-S direction traversing territories of varied climatic regime. According to Troll's classifications (OAS, 1969), its basin consists of two large zones: the "Tropical", in the North, and the "Temperate/Warm Subtropical" in the South. The annual rainfall is very high in the North-East of the basin (more than 2 400 mm) decreasing southerly to about 1 000 mm at the Del Plata estuary. Towards the West, however, there is a dramatic decrease in a desert area which receives 100 mm of rainfall or less. The river water is warm, with a gradual southward reduction. Bonetto (1976) gives an annual mean of 25°C near the confluence with the Paraguay river, decreasing to 21.9°C, in 1968, in the Santa Fe-Parana reach, 700 km downstream. The high number of existing dams on the Superior Parana together with the intense deforestation of the area (less than 3 percent of the native forests remain in Southern Brazil), are considered to determine possible climatic modifications, specially as concerns the rainfall regime, which could affect the hydrology, causing floods in large areas of the basin, resulting in widespread damage and economic losses. The 1983 floods in Argentina have also been related to the worldwide "El Nino" climatic disturbances which have had serious atmospheric repercussions mainly in the Southern hemisphere (Aisiks, 1984; Valdes & Ereno, 1984).

The Parana basin, as a component of the Brasilic Subregion of Neotropical America, has a highly diversified and abundant biota, even with the increasing human pressure on nature. Although exhaustive deforestation has occurred, large parts of the basin retain their original vegetation of which the most significant is the riparian forest and large quantities of aquatic and floating plants ("camalotales" and "embalsados"). The Parana has a high number of native fish species of good quality and considerable production (Bonetto & Castello, 1985). Most of the important commercial species are migratory, subject to long reproductive and trophic displacements (Bonetto, 1963; Bayles, 1973; Godoy, 1967). The dams on the Brazilian Superior Parana have no fishways to allow migration since it was believed that their negative impact could be substituted or mitigated through fish culture using hormonal induction techniques, even in the case of some Amazonian species (Machado, 1976; Machado & Alzuguir, 1976). Unfortunately the Superior Paranean ichthyofauna seems to be declining at an accelerated rate with regard to production, quality and quantity, and it has been pointed out that "piranas" (*Serrasalmus*) are presenting a

corresponding increase (Branco & Rocha, 1977). The recent completion of the Itaipu dam has drowned the Guayra falls, allowing the downstream migration of endemic species previously restricted to the river upstream of the falls. This addition to the Argentine ichthyofauna will have ecological consequences which are difficult to predict.

Argentine dam projects have fishways; however, they are completely different from one another, and are based on systems never experimented with Neotropical fishes, with the exception of fish ladders. In some cases, based on experience in the USSR, some equipment used for rescue and transfer operations of fish is being considered for use together with large fish culture installations (Bonetto, 1980; A & EE, 1982). All these projects entail large investments for the installation of devices whose effects on fisheries production are uncertain. Argentine Middle and Lower Paranean reservoirs will flood the major part of the flood plain. Interaction between the marginal lagoons and oxbow lakes and the main course of the river have been identified as being of great importance for the production of juvenile fish (Azevedo, 1962; Bonetto, 1963). Disappearance of these ecosystems from a functional point of view will surely negatively affect fisheries production. It should be pointed out that the Parana river has a rich fauna of tetrapods, linked to the aquatic system, which should be taken into account by all projects for regulating the river.

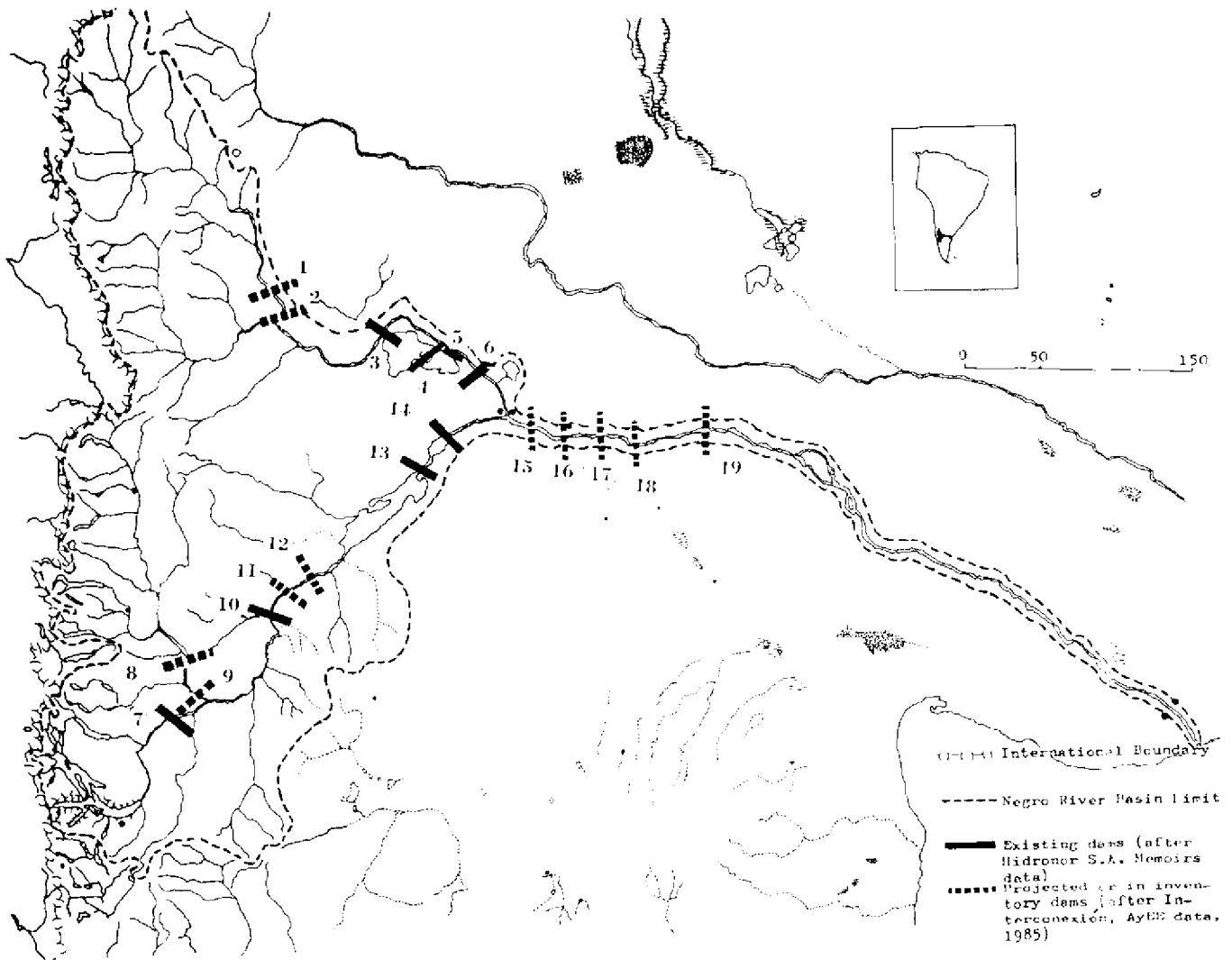
National and bilateral (Argentine-Paraguayan) dams on the Parana river were projected and begun after those of Brazil on the Superior Parana. Consequently, basic concepts and designs are different. In Brazil, as a result of the increasing demand for energy due to the industrial development of the last two decades, numerous hydroelectric dams have been built in the Southern states. Argentina, in collaboration with Paraguay, which needs less energy, began to reactivate its dam projects in the last ten years. Probably because of the unequal development requirements, there is no multinational programme to consider dam schemes on the same river basin with the idea of harmonizing the different projects and mitigating negative ecological side effects. In Argentina, for each dam project an independent state company has been created leading in certain cases to different engineering solutions of the same problems (as the distinct fishways projected for each dam).

3. The Negro Basin and its Regulation Projects

The Negro river flows across the Patagonian Region, where is found the extremity of the most important river system situated wholly within Argentine territory (Figure 2). Its drainage basin covers a surface area of 65 000 km² with a mean flow of approximately 1 000 m³-s. The catchment area is bordered by 600 km of the Eastern slope of the Andes. Two important tributaries originate in this area, the Neuquen and the Limay, which at an elevation of 225 m join to form the Negro river which flows to the East, and later to the south-east, crossing the arid Patagonic plateau, and discharging to the Atlantic, after covering a distance of 720 km. Clear evidence of the aridity of this plateau is that the Negro river has no tributaries all along its course. The river has excavated a valley 50 m deep at its mouth and 200 m deep at the Neuquen-Limay-Negro confluence, with a width that varies between 5 and 25 km, forming three distinct sedimentary layers on successive terraces. The mean slope of the river is 0.35 mkm⁻¹. Its valley has 400 000 ha of cultivable land, with frequent saline whitish spots of sodium sulphate and chlorides (Soldano, 1947), which necessitate careful management and treatment.

The Limay river discharge is mainly regulated by glacial lakes, highly oligotrophic, that appear interposed along its tributaries. On the other hand, the Neuquen has practically no lakes in its catchment, so that prior to being dammed, it produced frequent flash floods in the Negro valley, causing serious economic losses. At present there are several regulatory

Figure 11.2: Negro River Basin



Dams. (1). (2) El Chihuido I and II; (3) Portezuelo Grande; (4) Loma de la Lata; (5) Planicie Banderita; (6) Compensator of the system; (7) Alicura; (8) Collon Cura; (9) Alimenta de Alicura; (10) Piedra del Aguila; (11) Pichi Picum Leufu; (12) Michikhua; (13) El Chocon; (14) Arroyito; (15) Allen; (16) Roca; (17) Mainqui; (18) Regina; (19) Chelforo.

engineering works which to some extent diminish the flood peaks (Vidal-Pellegrini, Mari Menuco and Los Barriales system). Three hydroelectric dams have been completed in the Limay, and three more are projected which will transform the river into a long chain of artificial lakes.

The Negro river has no delta, but there is evidence of the development of a submarine one. The planned system of dams, Chelforo, Regina, Mainqui, Roca and Allen regulates the flow and have a total installed capacity of 1 376 MW (five dams, four of 264 MW and one of 320 MW) interconnected in 1984 also increasing the irrigated area and providing flood control. Adequate water management is necessary to avoid conflict between different water use options in this arid region (Bonetto et al., on press).

Patagonia is the most southerly biogeographical region of Neotropical America and it is characterized by its marked biotic poverty, with a notable climatic gradient from the Andean slopes which receive 2 000-3 000 mm of rainfall dropping to 500 mm at the source of the Negro river, and 100-200 mm towards the sea. On the Andean slopes a dense and characteristic *Nothofagus* forest called *Selva Valdiviana* develops with great splendour even though it is rather poor as regards the number of species. Its ichthyofauna is limited in production and this fact moved fish culturists to introduce salmonids at the beginning of the century without previous studies or planned fish culture activities. This brought fortuitous results and today salmonids cultures are becoming an important activity upon which depend recreation as well as commercial fisheries in the region.

4. Discussion of the Environmental Impacts of Regulation Systems on the Parana and Negro Basins

Comparing the regulation systems on the Parana and Negro basins, the following balance of benefits and possible negative effects can be discerned:

(1) The Negro basin dam project is wholly within Argentine territory; this fact simplifies harmonious planning, bureaucratic decisions and facilitates the dam construction.

(1a) Dams on the Parana river depend on the decisions of different governments with diverse interests and unequal possibilities to participate in the regulation programmes of the river, with obvious conflicts of interests.

(2) Because of point (1), the Negro basin regulation system is much easier to develop according to the real possibilities and interests of the country including its hydropower needs, resulting in a much more regular rhythm of dam construction.

(2a) On the Parana, the Argentine programme is much delayed in comparison with that of Brazil and Paraguay, obliging the government to adapt to what has been constructed in the upper reaches of the river and its ecological effects, trying at the same time to harmonize the Argentine interests with those of the neighbouring countries, where necessary. This leads to certain technical complications depending upon bureaucratic decisions.

(3) The Negro basin programme will not affect human populations or their economic activities and does not call for complex engineering solutions.

(3a) The Parana basin programme can affect one of the richest and more densely populated areas in Argentina, requiring in the case of structures built in the plain, specialized engineer works and high investments

(4) The regulation system proposed for the Negro basin does not present erosive side effects of particular significance.

(4a) Those of the Parana might produce profound changes of the natural sediment regime which could affect the equilibrium of the delta and estuary with negative effects on densely inhabited areas of great economic importance.

(5) The quality of water in the Negro river system will be less affected by human activities. Maintenance and control of water quality does not raise problems at the moment and will be easily dealt with if they arise in the future.

5a) Water quality in the Parana river and its future man-made lakes will depend upon policies to be adopted throughout the basin, in Argentina and beyond its frontiers. If the river is not yet affected to any significant level by human settlements, this will surely not be the case as the population increases and industry develops encouraged by the abundance of inexpensive hydroelectric energy.

(6) The biota of the Negro system is limited if compared with that of the Parana, and on this account the dams will have little impact on the natural environment. Native ichthyofauna of low diversity and production has not been significantly modified, with the exception of certain catfish that diminished as a result of salmonid introduction and which might benefit from the construction of dams.

(6a) The Parana biota, much richer, will suffer a severe impact due to the dams in Argentina. The conservation of fisheries will require large investments for the construction of fishways of doubtful efficiency. Undesirable fish species as "piranas" will probably proliferate as happened in Brazilian man-made lakes. Generally a profound impact on the regional environment should be expected, with the loss, in the case of Middle Parana, of an entire natural and biogeographically unique South American biotic system (Smirnov,1982).

(7) Significant water-borne diseases are not known in the Negro basin. Some trematods and insects have been reported, of of no real sanitary importance.

(7a) The Parana river presents the potential risk of diverse entomoepidemiological diseases, although so far the endemism is low, even though hematophagous insects such as mosquitos and simuliids are temporarily abundant and harmful. The greatest sanitary problem is Schistosomiasis, propagated by several gasteropods of the genus *Biomphalaria*. Its propagation on the Superior Parana seems to be fairly recent and even though the eradication of the detected focus has been successful, this disease could spread into Argentine limnobiomes of the projected regulation system, due to the presence of intermediary molluscs which host the parasite *Schistosoma mansoni*. The prevention of southward extension of this disease will require an efficient and well-coordinated sanitary policy.

(8) The problems resulting from the submersion of vegetation in the Negro basin are moderate and limited to the narrow fringe of Andean forest. The upper reservoirs will probably affect only part of the lower fringe of Andean forest which is in any case abundant in the upper catchment. This would only affect the conservation of the trees involved

because the decomposition of the flooded biomass is extremely slow and the problem a long-term one because of the low temperatures and the ecology of the area (Bonetto *et al.*, 1976). No problems due to floating plants will arise which might interfere with the operation of dams.

(8a) Abundant masses of marginal forests and swamps of the alluvial valley will be flooded by dams on the Argentine Parana, making it necessary to carry out expensive clearing programmes in order to avoid the active decomposition in the subtropical and tropical climatic conditions of the Parana basin. If these are not carried out water quality might be severely affected. At present a marked reduction of the dissolved oxygen is common in the deepest layers of the man-made lakes of the Superior Parana in summer. Besides, the artificial lakes of the Middle Parana might be massively invaded by aquatic weeds such as water hyacinth, *Eicchornia spp.*, which floats down mainly from the Paraguay river. To this natural floating mass has to be added the biomass that would be produced in the flat areas of the projected lake margins, specially at the confluences and in the alluvial flood plains. This aquatic floating vegetation would be a serious threat for the operation of dams and cause deterioration of limnological conditions, hamper navigation and limit the recreative use of the artificial lakes.

(9) The regulation of streamflow in the Negro basin will allow the improved use of available water whilst eliminating or drastically reducing floods. Its reservoirs will also serve to irrigate arid land on the Patagonian plateau and produce substantial amounts of energy (the Neuquen and Limay sub-basins having a much higher potential than that of the Negro river), without large investments and significant ecological impacts.

(9a) Even if taken into account that the Paranean projects, when functioning, will produce larger quantities of energy, it should not be forgotten that these dams will have a very complex regulatory effect, with a reduction of the low-water and an increase in the duration of high water levels, and only a limited action in the prevention of floods. Climatic effects such as increased rainfall and floods might be expected. The Parana is subjected to a programme of intensive dam construction primarily intended for energy production, excluding any other possible secondary benefit, when in fact flood control is a very serious and urgent problem. The many ecological impacts will be of such severity as to mitigate the positive effects, justifying appropriate investments for integrated studies of an adequate level to cope with these aspects. A carefully planned joint management of the future system of dams will be difficult but important, because of its complexity and the necessity of a dynamic agreement on general objectives.

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PAPER 12

ENVIRONMENTAL IMPACTS OF SADDAM DAM ON THE JAZIRA REGION (NORTHERN IRAQ)

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1. Introduction

More than fifty percent of the total area of Iraq (about 435 000 km²) is arid and semi-arid. Consequently the efficient and economic utilization of its water resources is extremely important. Fortunately Iraq is endowed with two great river systems, the Euphrates and Tigris, both of which rise in the Eastern mountain ranges of Turkey. The Euphrates receives no tributary in Iraq whereas the Tigris receives four, all of which rise in the mountains of Turkey and Iran. During the last forty years, Iraq has built a series of dams and reservoirs, mainly for irrigation purposes. Saddam dam on the Tigris in Northern Iraq is one of the most recent and largest. A big lake (reservoir) has formed as a result and a complex network of irrigation canals is being planned. The present paper will concentrate on the environmental impacts of the two canals that will divert water from the right bank of the Tigris at the dam westward and southward for the irrigation of the Jazira region of Northern Iraq (Fig. 1).

2. The Jazira region

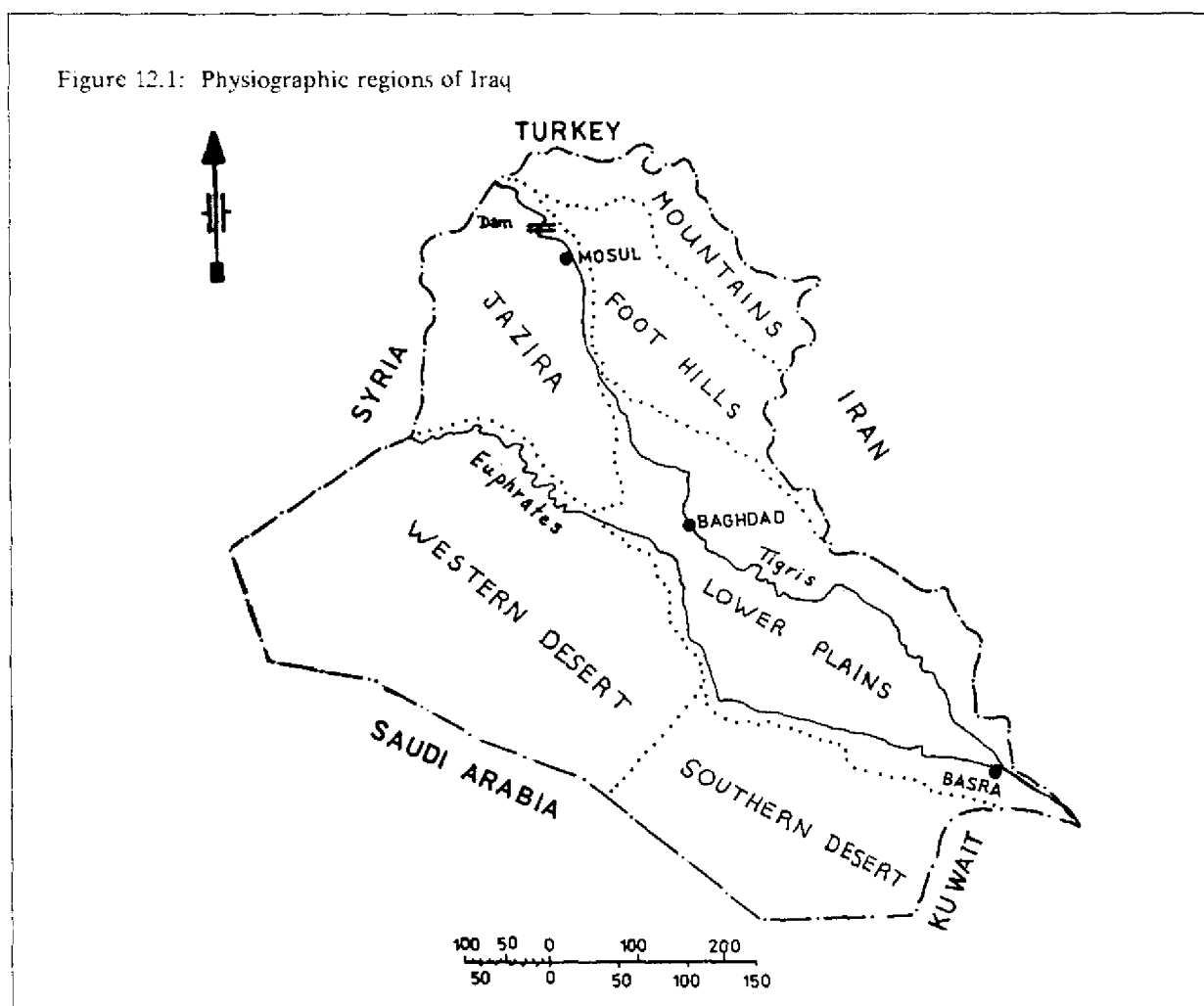
The dam is located about 60 km North of Mosul, the second largest city in Iraq, after Baghdad, and at the upper limits of the Jazira region. This Jazira (island) region is a low plateau sloping from an elevation of about 500 m near the town of Sinjar in the North to 275 m in the Southwest and 100 m in the southeast.

For present purposes the Jazira will be divided into two regions, the lower Jazira and upper Jazira (Fig. 2). The soils of the upper Jazira with which we are mainly concerned here, are distinguished by a fine structure and a reddish-brown colour, with relatively high amounts of organic matter in the top soil. They are rather fertile and can produce good crops if enough water is available. Gypsiferous soils are found in the upper Jazira area (Guest, 1966; Thalen, 1979; Unesco, 1975).

2.1 Water resources of the region

The mean annual rainfall in the Jazira region is presented in Fig. 2. It can be seen that rainfall decreases progressively in a southerly direction. There is, in addition, a moderate amount of groundwater exploited by means of dug wells or outcropping in natural springs.

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Many villages are concentrated around such springs and wells. Numerous Kahrizes (ancient method of raising water from ground level) are found in the moist upper zone of the region (Thalen, 1979; Jawad et al., 1982). Water quality however is a big problem because the groundwater usually has a high concentration of dissolved salts.

2.2 Vegetation

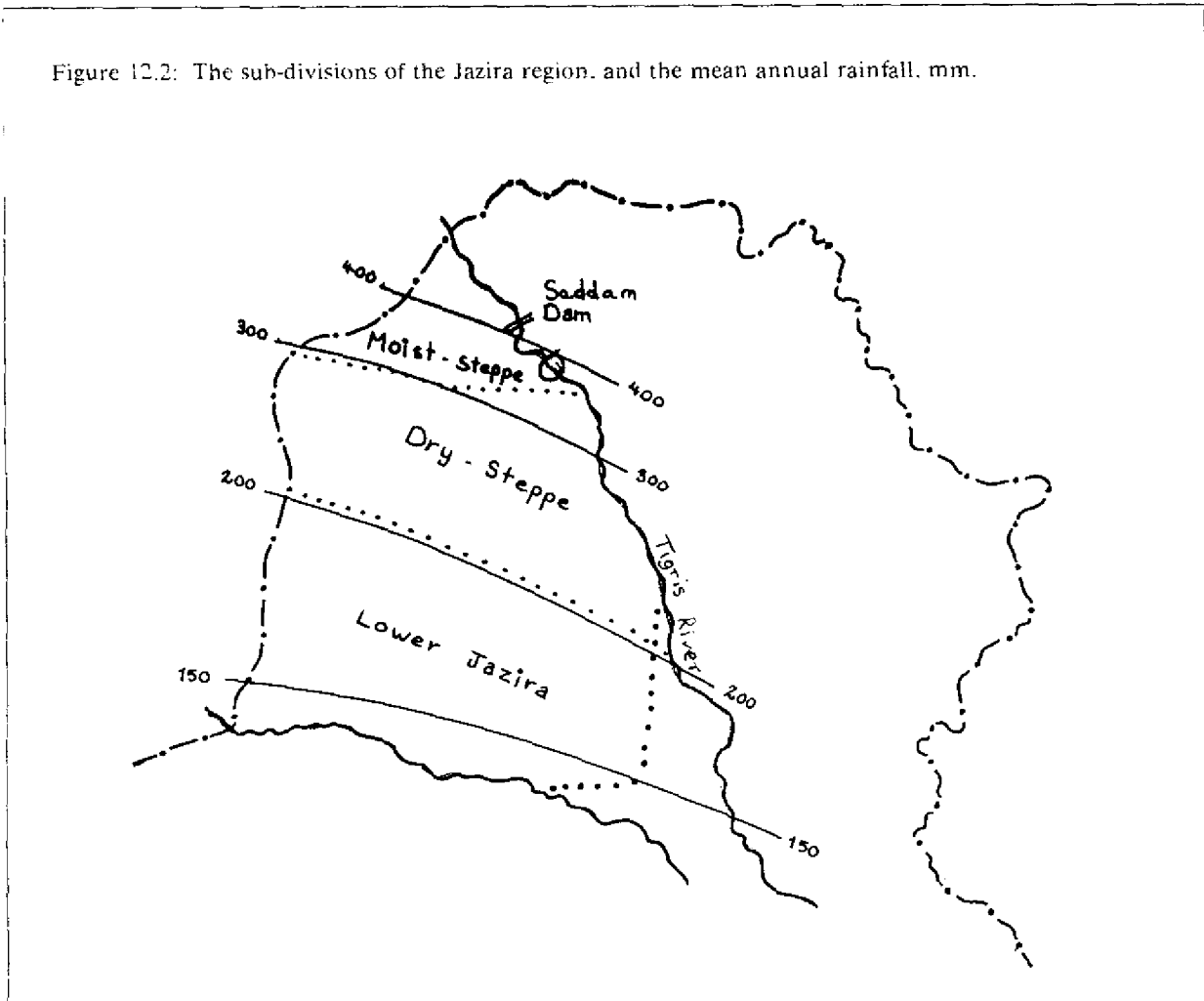
Over-grazing and rain-fed farming have almost completely destroyed the natural range lands of the region. The Jazira area has lately become almost devoid of those useful range species which used to occur, such as *Artemisia herba-alba*, now replaced by such undesirable species as *Artemisia scoparia* and *Peganum harmala*. The most widely distributed annuals are *Poa bulbosa* with *Carex stenophylla* and *Ranunculus asiaticus*.

2.3 Population

In the past (40-50 years ago) and even today, though to a limited extent, three types of rural populations have inhabited the Jazira region: the nomads or unsettled bedouins, the

semi-nomadic people, mostly in small villages, and the settled urban people engaged mainly in crop production.

Figure 12.2: The sub-divisions of the Jazira region, and the mean annual rainfall, mm.



3. The environmental impacts of the project

Transferring water from any source to arid and semi-arid zones will necessarily give rise to certain changes and disturbances. In the present paper the impacts of the two main canals running westward and southward from the dam and the reservoir formed North of it will be examined. The main purpose of the canals is the supply of irrigation water to ensure an increase of yields. Earlier studies (Greater Mussayeb Irrigation Project) in Southern Iraq (Unesco 1980) show that irrigation guarantees an increase in the yield but that a price must be paid for these higher yields. Only very careful management and real understanding of how irrigated agriculture functions in arid and semi-arid zones can maintain this price at an acceptable level.

Clor

For convenience and on the basis of rainfall, climate, land-use and population, the upper Jazira will be further divided into two zones or ecotypes: the moist steppe and the dry steppe (Fig. 2). The environmental impacts of the project on these two zones will be examined in detail.

3.1 Impact of the reservoir

A big lake has been formed North of the dam. This will have impacts on the environment of the vicinity due to: (a) the new water regulation system, (b) the disappearance of the original ecosystem in the flooded area, (c) the new micro-climate which will be cooler and perhaps moister in the summer, (d) percolation resulting in recharge of neighbouring aquifers, (e) the changed agricultural pattern, (f) the socio-economic changes; the area becoming an attractive touristic and summer resort with new settlements and population increase in the vicinity of the lake. As a consequence more jobs will be available, more road systems and other mechanization processes will be introduced into the area and pollution will be increased. A higher standard of living with new life styles will most probably take the place of the old traditional rural life.

3.2 The impact of the canals on the moist steppe zone

With a mean annual rainfall of 300 to 425 mm, this zone of light relief includes most of the area North of Tal Afar and Sinjar. The soil is deeper and rain-fed agriculture is in general successful except for occasional dry periods due to the irregularity of rainfall. There are several small towns and numerous villages in the area. The main crops raised are wheat and barley. Sugar beet has been introduced recently. The fallow system is still followed with no crop rotation. Limited amounts of fruit and vegetables are produced in the vicinity of springs.

3.2.1 Irrigation

The Western canal will pass through this zone only, whereas the Southern canal will run first through this zone and then extend to the dry steppe zone. Irrigation in the moist steppe zone is supplementary and only used when water shortages occur. The main impacts can be summarized as follows:

- (a) Salinity problems: The area is generally naturally drained, and if irrigation water is applied carefully and only when needed, salinity can be avoided and controlled.
- (b) With enough water, crop yields will be increased. Provided with a good extension service, farmers who at present usually do not use fertilizers will be encouraged to do so, and this will further raise the yield and affect the standard of living.
- (c) Water regulation and distribution will call for a new system of land tenure. Good land use will also require good water management and water distribution policies.
- (d) Increased yields will lead to a higher standard of living and to more modern social facilities.
- (e) With extensive agriculture and modern technologies, the fallow system is likely to be abandoned. This will lead to the adoption of crop rotations and diversification.
- (f) Orchards and market gardens will be introduced, together with industrial crops such as sugar beet, cotton, oil seed crops, etc.
- (g) With the availability of raw materials, food industries will be introduced, and this will make for more jobs and higher incomes.

- (h) The natural rangelands will be reduced in area but possibilities for green pasture production will be increased to provide for livestock.
- (i) Increased urbanization will usually bring with it its own undesirable effects, new types of housing, new habits, diseases and sanitation problems. Such problems might be overcome by modern facilities and services, for example: electricity, roads, schools and hospitals.
- (j) The hydrology of the irrigated areas might be modified by rising groundwater levels which in turn will affect plant-soil-water relationships.
- (k) Few pesticides are used at present but with extensive irrigated agriculture, pesticides will be introduced together with some of their harmful effects, including pollution of drainage water.

3.3 The impact of the Southern canal on the dry steppe zone

The Southern part of the upper Jazira consists for the most part of a flat plain which receives limited rainfall (mean annual 200-300 mm) and is cut here and there by numerous wadis. Thus dry farming in this area is often risky, especially in the South which is devoted to rangeland used in the past by nomadic bedouins. Recently, however, the pressure of increased population has been pushing rain-fed farming further and further South into the more arid lower Jazira region.

The main impacts of the Southern canal on this dry steppe zone can be summarized as follows:

3.3.1 Irrigation

Big irrigation schemes are under construction which are expected to result in the following favourable effects:

- (a) Improved land-use and distribution and new water management policies for efficient utilization of water and more economic crop production.
- (b) Agricultural areas will be greatly increased, adding to the self-sufficiency of the country. Increased use of fertilizers is expected.
- (c) Crops other than wheat and barley will be introduced.

Unfavourable effects will include:

- (a) Reduction of the rangeland areas.
- (b) Irrigation and drainage water may become vectors of disease and parasites.
- (c) As mentioned earlier, use of large amounts of pesticides will increase the dangers of pollution, especially if misused.

3.3.2 Population

One of the outcomes of irrigated agriculture in this zone is settlement at the expense of nomadism, resulting in large-scale socio-economic changes. Traditional bedouin life styles and habits will be drastically altered. New villages and population centres will be established and modern facilities such as houses, schools, clinics, electricity, television will appear.

3.3.3 Salinization

Experience in the Greater Mussayeb Project showed that the main problem of irrigated agriculture in arid and semi-arid regions is salinization and that the key to the solution lies in the interrelated parameters of the irrigation and drainage systems. This requires efficiently managed, well-established and carefully maintained drainage systems backed up by effective extension services. Unless these management requirements are met the irrigated system can easily collapse.

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PAPER 13

INDIA'S LARGE WATER PROJECTS AND THEIR IMPACTS ON ENVIRONMENT

K.S. Murty

Abstract

Extensive irrigation systems were in existence in India in Ancient times as evidenced by Harappa and Mohen-jo-Daro and the Grand Anicut on the Cauveri. The Yamuna Canal system was developed during the Mughal Period (14th to 18th centuries). Several famines in the nineteenth century in several parts of the country set some of the British engineers like Sir Arthur Cotton and Proby T. Caultley thinking and they were responsible for the development of the Godavari, Krishna and Ganga canal systems. While important projects were undertaken in the early part of the nineteenth century, it was only after India obtained independence that gigantic projects were built on an unprecedented scale which enabled the country to attain self-sufficiency in food, produce hydro-power (14 000 MW) and provide drinking water for many villages. India has invested over MRs. 100 000 in the last three decades and built over 600 storage dams of various sizes accounting for a storage capacity of 160 Gm³ for irrigation, flood control and power generation. The irrigation potential has been raised to about 65 Mha.

However, these achievements have not been accomplished without affecting the environment in the catchment and command areas. For instance, the Nagarjunasagar project on the Krishna river is said to have been responsible for the increase of fluoride content in the groundwater to almost 25 ppm. This resulted in a disease called "fluorosis" which has incapacitated many people in the area and has also been reported from Tamil Nadu, Karnataka and Punjab. Besides, large scale evacuation of people from the areas that were to be submerged by the reservoir waters had to be effected and monuments of archaeological interest had to be shifted to safer areas when the Nagarjunasagar and Srisaïlam projects were undertaken.

In Haryana and Punjab States, about 1 Mha of land became waterlogged. 7 Mha of saline and alkali soils have developed in the country. Equally important is the deforestation problem. For instance, the Idukki reservoir in Kerala caused the loss of 50 percent of the forest cover in the area. Between 1951 and 1976, deforestation for various purposes was resorted to on 4.14 Mha of which the share of the major river valley projects is 0.48 Mha and that of agriculture is 2.51 Mha.

The Government of India has become quite conscious of the serious nature of the environmental and ecological imbalance that major projects have caused and has refused clearance for the Silent Valley Project, which could have produced 120 MW of power, but in the process some of the most precious and unique tropical forests would have been lost for ever.

1. Introduction

Water is the heart of the Indian economy. Indian civilisation grew on the banks of mighty rivers and the latter have always been worshiped as goddesses. The art of irrigation, has been practiced in India from very early times. One of the oldest dams in the world is the Grand Anicut Dam, constructed across the river Cauvery, during the second century of the Christian era, consists of a weir approximately 300 m long, 12 to 18 m wide and 5 to 6 m high, capable of irrigating as much as 250 000 ha. A number of canals were constructed during the Mughal period (14th to 17th century) under the guidance of Ali Mardan Khan, prominent amongst which are the Western Jamuna canal and the Tungabhadra canals constructed by Krishnadeva Raya in 1529. However, several famines affected many parts of the country in the nineteenth century leading British engineers Sir Arthur Cotton and Proby T. Cautley to undertake the construction of the Godavari and Krishna delta irrigation schemes in 1850, of the Cauvery in 1836 as well as several others in the Punjab. After Independence India built many major, medium and minor water projects in order to provide food for the increasing population generate power and control floods, also supplying drinking water to many villages.

2. Major River Basins

River basins of 20 000 km² catchment area and above are termed major river basins and there are fourteen such basins in India (Rao, 1975): the Indus, Ganga, Brahmaputra, Sabarmati, Mjahi, Narmada, Tapi, Subarnarekha, Brahmani, Mahanadi, Godavari, Krishna, Pennar, and Cauvery. Their total catchment area is estimated to be 2.58 Mkm² and the total annual surface flow is about 1 897 000 Mm³, of which about 451 000 Mm³ are utilized for various purposes. These include a hydropower generation (installed capacity of 14 578 MW) and a further irrigation potential of about 65 Mha (Johnson, 1979).

3. Major Water Projects

India has so far invested over MRs. 100 000 in the last three decades and built over 600 storage dams of various sizes accounting for a storage capacity of 160 000 Mm³ for irrigation, flood control and power generation. In spite of droughts and floods that have plagued the country, the food grains production reached 146 million tons, which is still short of the target of 159.2 million tons set for 1985-86. The total installed capacity of hydro-electric energy in 1951 was just around 2 300 MW. Several multipurpose projects built on the major rivers of India contributed to these achievements in food production, raising of irrigation potential and hydro-power generation, among which may be mentioned the Bhakra-Nagal, Hirakud, Rihand, Nagarjunasagar, DVA, Gandhisagar, Ranapratapsagar, Sharavathy, Idduki and Srisaigan projects built in the post-Independence period (Figure 1 and Table 1).

4. Impact on Environment

Development activities have given rise to a variety of environmental impacts which can be classified as physical, chemical, biological, social and economic (Pendse, 1986). With its large water projects India has not escaped these impacts though the benefits normally outweigh the negative environmental side effects even if the latter have, in some cases, been tragic.

Bhakra project

The tail water of this project is utilised for irrigating 0.68 Mha in Haryana, 0.55 Mha in Punjab and 0.23 Mha in Rajasthan, through a network of 174 km of main canal, 1 110 km of

Table 1: Some Major Water Projects and Relevant Data

Project/ River	Irrigation potential (Mha)	Power potential (MW)	Other purposes
Bhakra/Sutlej	14.6	1050	Flood control
Beas/Beas		1350	Flood control
Damodar/Damodar	3.7	104	Flood control
Gandak/Gandak	1.47		Flood control
Hirakud/Mahanadi	0.25	270	Flood control
Idukki/Periyar		390	
Kosi/Kosi	1.10		Flood control
Konya/Konya		960	
Kundah/Kundah		535	
Matatila/Betwa	1.65		
Nagarjunasagar/ Krishna	0.83	100	
Rajasthan Canal	1.15		
Ramganga/Ramganga	0.57		
R.P. sagar/(3)Chambal	0.56	386	
Rihand/Rihand		300	
Srisaïlam/Krishna		770	
Sharavati/Sharavati		891	
Sabarigiri/ Pamba & Kakki		300	
Tungabhadra/Tungabhadra	3.32	126	
Ukai/Tapi	0.16	300	Flood control

(Rao, 1975; Sharma & Coutinho, 1977; Chaudhuri, 1976; GSI, 1975)

main branches and 3 379 km of distributaries. In Haryana on nearly 0.65 Mha the water table has risen to a level only 3 m below the ground surface and a further 0.3 Mha will soon be in the same situation. According to a study conducted by the Administrative Staff College of Hyderabad, 10 Mha of canal irrigated land have become waterlogged and another 25 Mha are threatened with salinity (Sharma, 1984). In Punjab, on 10 Mha in 1955 increasing to 16 Mha by 1962 the level of the water table ranged from 0 to 1.53 m below ground level due to canal irrigation (Singh, 1983) resulting in an annual loss of agricultural production of MRs. 3.5 to 4.0. The Rajasthan canal, fed by a feeder from the River Sutleg at Harike, has also caused similar waterlogging problems in about 10 percent of the project area of 7 000 km² besides forming a shallow hard pan on 0.11 Mha accompanied by a decline in the livestock population of the area (Times of India, 1983).

Idukki project

5 776 ha of land were submerged by the reservoir of this project and about 5 000 people had to be resettled, which caused social, political and economic problems to the Government of Kerala (Trisal, 1986). In Idukki district alone, hydro-electric projects and colonisation have consumed nearly 11 500 ha of forest damaging the flora and fauna of the area. According to a survey conducted by the Zoological Survey of India, animals such as tigers, panthers, bears, gaur and barking deer have either disappeared or become rare in this area. (ZSI Report, 1985).

Nagarjunasagar and Srisaïlam projects

Both these projects have been built on the Krishna river; while the former was completed years ago with the canals remaining incomplete, the latter is nearing completion. A consequence common to these two projects is that the waters of their reservoirs submerged relics of great archaeological interest from ancient and medieval India including temples of typical Chalukyan style. Though not on the scale of the Egyptian temples salvaged when the Aswan dam was built on the Nile, the successful transfer of the archaeological remains from the Nandikonda valley and temples from Sangameswaram area to safer sites constitutes a glorious chapter in the history of archaeology (Sarma, 1984; Ramaswami, 1984) (Figs. 2 and 3). Unesco and many foreign governments collaborated in this task. The area submerged in the case of the Srisaïlam project is 655 km² mostly of rich land. More than 100 villages were submerged in the Kurnool and Mahaboobnagar districts and 20 000 families had to be resettled elsewhere.

More tragic has been the spread of a disease called "fluorosis" that has incapacitated many people in the area irrigated by the Nagarjunasagar canal system, particularly in the Nalgonda, Mahaboobnagar and Prakasam districts of Andhra Pradesh (Fig. 4). Though reported as early as 1937 in the Nellore district (Sriramachari, 1983), the increased incidence was perceived after the completion of the project and the knock-knee *genu valgum* deformity was prevalent in children 8 - 10 years old, its incidence being as high as 17 percent in some areas (Krishnamachari, 1974). The fluoride content of well water ranged from 0.5 mg l⁻¹ to 20 mg l⁻¹ (Rao et al, 1980). This disease has been reported in the Coimbatore district after the completion of the Parambikulam project and the opinion that it is associated with the waters of the reservoirs of the projects in these areas has received support. Fluorosis which was confined earlier to Andhra Pradesh, Tamil Nadu, Punjab and Uttar Pradesh has now been reported in Haryana, Delhi, Rajasthan, Gujarat, Madhya Pradesh and Karnataka (Susheela, 1985).

Other Projects

In the case of other projects, the impact has been mainly physical. Over 47 000 persons were displaced when 46 000 ha of land were submerged by the pond of the dam on the Rihand river (Jain, 1963). The lake formed by the Gandhisagar dam on river Chambal submerged 228 villages, 29 600 ha of cultivated land, and affected a population of 51 500 people (Mane, 1963). The Sharavti project submerged roads and 7 200 ha of land and affected 3 847 families in 280 submerged villages (CBIP, 1964).

General

Between 1951 and 1976, deforestation affected 4.14 Mha in the country, of which the share of the major river valley projects is 0.48 Mha and that of agriculture is 2.51 Mha. This has resulted in soil erosion on a large scale in the hilly regions and a reservoir siltation rate far in excess of estimates. The life of such reservoirs has been reduced and the very purpose of such projects is now being questioned in view of the high escalation in the cost of their construction as a result of long gestation periods. There is rethinking on the part of the government concerning these large water projects where the environmental impact is likely to be great. Clearance of such projects has either been refused, or withheld. The Silent Valley Project proposed in Kerala has had to be dropped because its execution would have submerged some of the most precious and unique tropical forests.

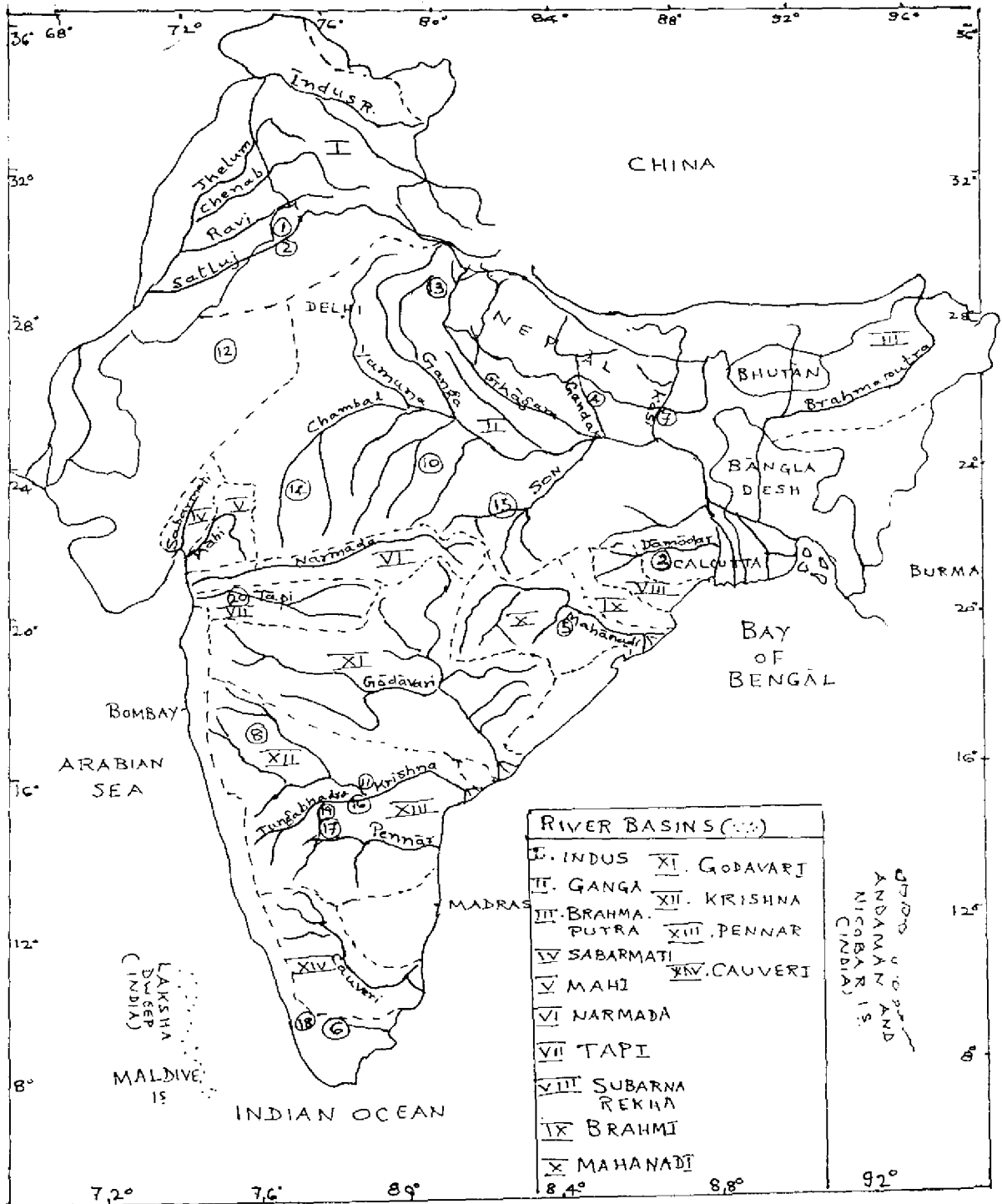


FIG. 1. INDIA - RIVER BASINS AND SOME MAJOR PROJECTS.

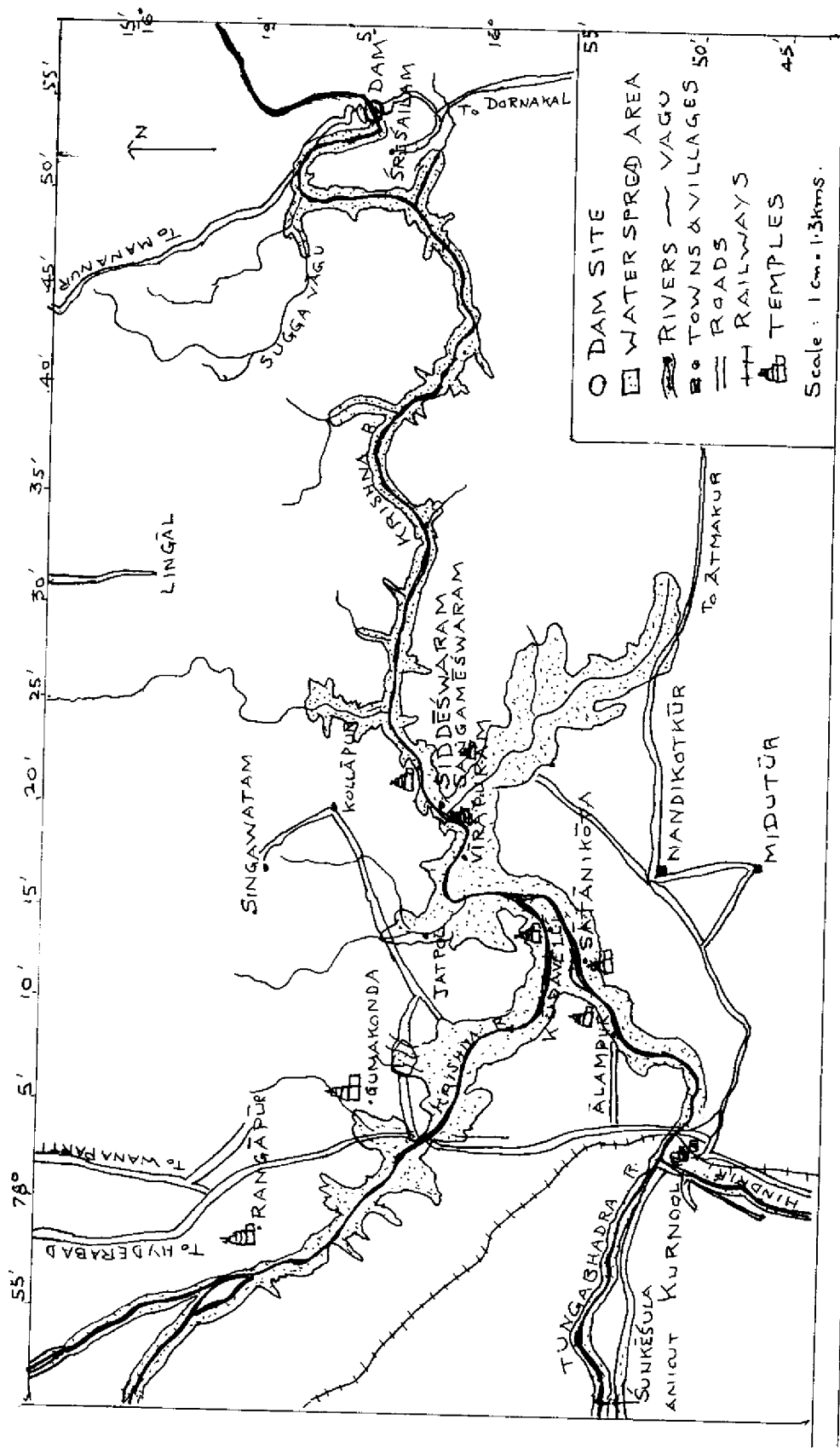


FIG. 2. SRI SAILAM H.E. PROJECT: RESERVOIR SPREAD AND SUBMERSIBLE AREA WITH TEMPLES

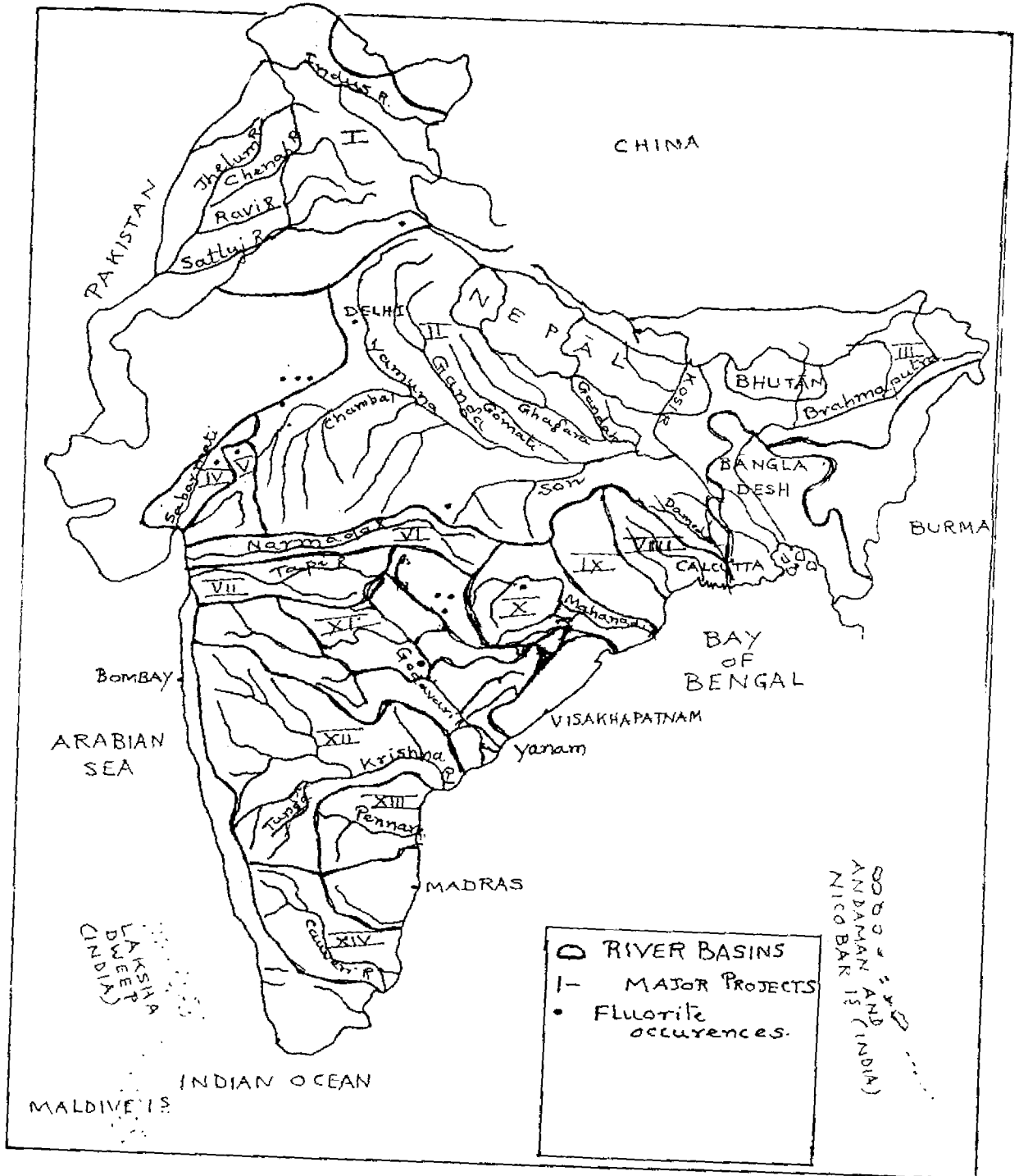


FIG 3 INDIA : RIVER BASINS AND MAJOR PROJECTS.

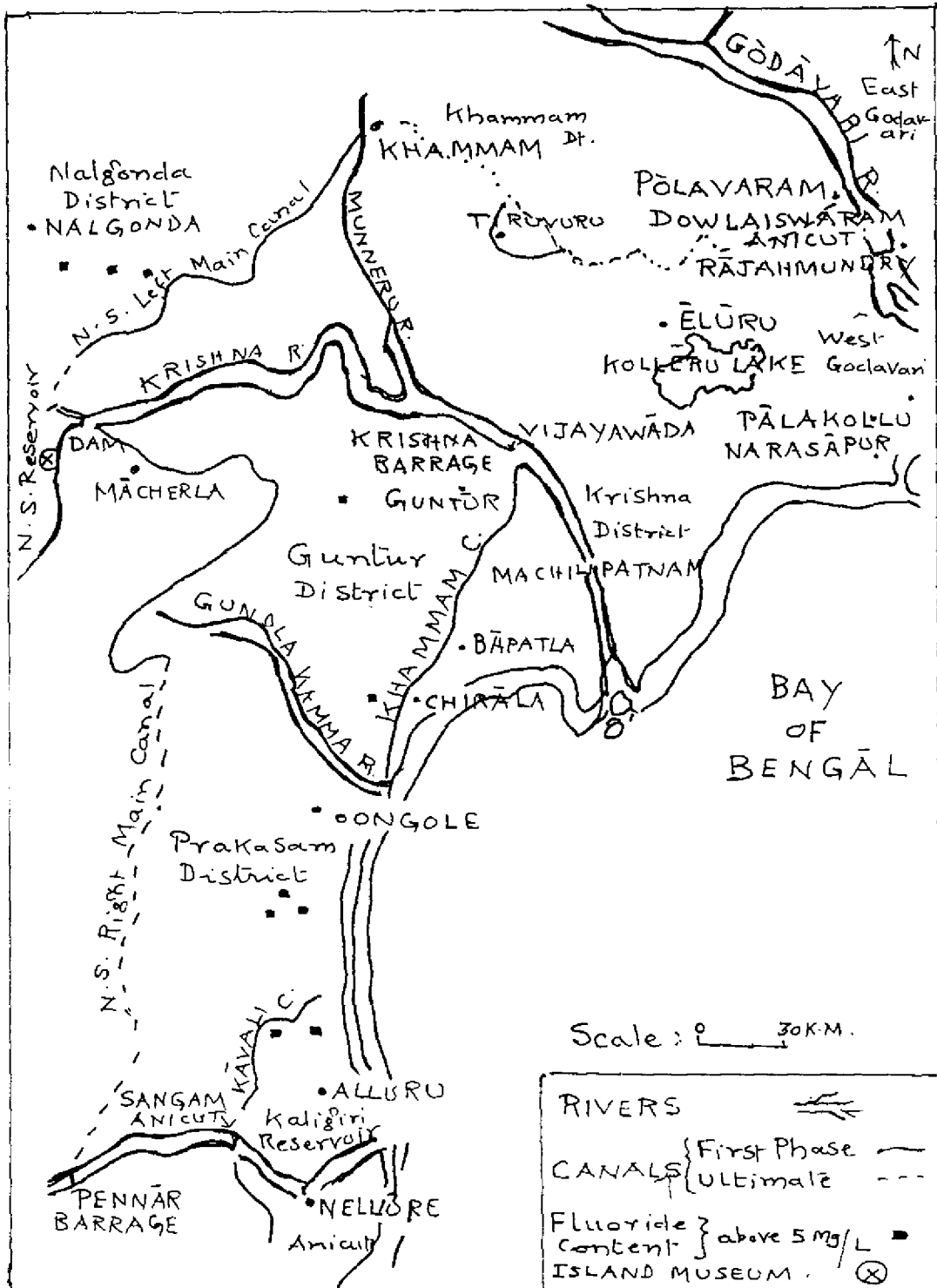


FIG. 4. LAYOUT OF NAGARJUNASAGAR CANALS

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PAPER 14

ADVERSE IMPACTS AND ALTERNATIVES TO LARGE DAMS AND INTERBASIN TRANSFERS IN THE COLORADO RIVER BASIN, U.S.A.

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1. Introduction

The Colorado River is one of the most highly dammed and regulated rivers in the world. From its sources in Western Colorado and Southwest Wyoming, the river flows 2 240km in a southwesterly direction to the Gulf of California (U.S. Department of the Interior, 1985). It drains an area of 619 520 km² in the U.S.A. Parts of the states of Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona and California, as well as a portion in Mexico, lie within the hydrologic basin (Figure 1).

The Colorado River Basin is arid or semi-arid and the river carries a mean annual virgin flow of 16 to 18 x 10 GM³ at Lee Ferry, Arizona (dividing point between the Upper and Lower Basins). The control of surface flows in the basin has been very extensive. There are more than 20 large dams on the Colorado River and its tributaries. The initial major storage feature on the main stem is Hoover dam which was completed in 1935. Construction of other storage and diversion features in the Lower Basin during the first half of this century assured almost complete control of the river below Lee Ferry. These structures include Laguna, Imperial, Parker and Davis dams (Figure 1). Morelos dam is located just below the international boundary with Mexico and is the last dam on the Colorado River. Major storage projects in the Upper Basin began in the 1950s, with the most important feature being Glen Canyon dam which was completed in 1964. Other important features include Fontenelle, Flaming Gorge, Navajo, Blue Mesa, and Morrow Point dams. In addition to these storage projects, a substantial part of the surface water supply is diverted out of the basin. These diversions amount to about 6 000 Mm³ and could ultimately increase to about 10 000 Mm³.

Water resources planning in the basin has been concerned mainly with full development of available supplies and the basin is now closer than any other basin in the U.S. to utilizing the last drop of available water for human consumption. Such attitude has its roots in 1922 when the basin was artificially divided into an Upper Basin consisting of the states of Colorado, Wyoming, Utah and New Mexico; and a Lower Basin consisting of Arizona, Nevada and California. A high flow for the Colorado River, presumably 20.3 x 10 GM³ per year was assumed and each sub-basin was apportioned the right to an annual consumptive use of 9.225 x 10 GM³. The 1922 Compact also dictates that if a state cannot use all the water to which it is entitled, the water can be used by downstream users. Since the Lower Basin states, with the help of massive federal government subsidies, developed their water resources first, unused water from the Upper Basin is currently being used in the Lower

Basin. Partly out of a belief that they should develop their water rights before it is too late, the Upper Basin states are now taking the path of pre-emptive development. They are promoting water projects that are economically and environmentally unjustifiable and many such projects are designed to supply water uses that are of low value or little demand.

2. Environmental Impacts

In general, the principal physical changes resulting from the construction of reservoir projects include inundation of land forms, loss of free-flowing streams and associated recreational opportunities, sediment trapping, reservoir and stream bank erosion, increased evaporation and salt concentration, and thermal stratification. On the other hand, the most important physical changes downstream from impoundments include flow modification (depending on reservoir operations), changes in stream morphology or configuration, and modification of downstream water temperature and concentration of dissolved solids (Ortolano, Ringel and Jones, 1973).

In the Colorado River Basin, increased surface areas have led to increased evaporation from the system. Lake Mead, for example, has an annual evaporative loss of 1 200 Mm³ or about 16 percent of the water made available by the reservoir (Langbein and Hoyt, 1959). In addition, the net effect of evaporation and the dissolution of minerals has been a higher load of dissolved solids below Hoover Dam than above it (Hem, 1965). Recently, however, Paulson (1983) suggested that because of the reservoirs, total dissolved solids (TDS) concentration in the Colorado River cannot be modeled by simple flow v. TDS relationships. In other words, concentrations do not necessarily increase as dilution factors decrease. In fact, he argues that rates of dissolution and precipitation are related to complex interactions between individual salts and the physical/chemical properties of the reservoirs, including temperature, phytoplankton productivity and sediment diagenesis.

The Colorado River once had the highest rate of endemic aquatic life of any river in North America (Carothers and Johnson, 1983). However, due to drastic alteration of sediment discharge, flow regime, temperature variation, and the introduction of exotic plant and animal species, changes in the river's ecology have been great. The impacts of Glen Canyon Dam, for example, have been to reduce sediment discharge through the Grand Canyon from an average of 140 million tons per year to an annual average of 20 million tons (Carothers and Johnson, 1983). Post-dam variations in temperature have also been reduced to about 3°C from 1°C in winter to 4°C in summer as compared to pre-dam river temperatures of 4°C (winter) and 24-30°C (summer). There are now 27 fish species that inhabit Glen and Grand Canyons, 70 percent of which are introduced and non-native. Five of the eight native species have disappeared and three of these (Boneytail chub, Colorado chub and Colorado squawfish) are endangered (Carothers and Johnson, 1983). In addition, Lake Powell retains 70 percent of dissolved phosphorous and 96 percent of total phosphorous, creating phosphorous-limited conditions and declining productivity in the upper part of Lake Mead (Messer, Israelson and Adams, 1983).

Environmental assessment methodologies, developed in the early 1970s, have been concerned mainly with the impacts of individual projects. There is now considerable concern that the total interrelated and cumulative impacts of existing and proposed projects are considerably more than the sum of the individual project impacts. For example, proposed water storage projects in the Upper Colorado River Basin are estimated to cause the loss of 341 km² of important wildlife habitat. When added to the more than 1 165 km² of wildlife habitat throughout the Upper Basin which have already been lost due to existing water projects, the adverse cumulative impacts are substantial (El-Ashry and Weaver, 1977).

In addition, irrigation return flows and stream flow depletions would adversely affect critical habitat for Colorado River endangered fish species and trout fisheries. However, these impacts have only been assessed on an individual project basis. While any one project may not cause changes in these critical habitats to a degree that can be determined as detrimental, the U.S. Fish and Wildlife Service believes that the cumulative effects of all the projects in the basin would have detrimental impacts of sufficient magnitude to jeopardize these endangered species (El-Ashry and Weaver, 1977).

Salinity, or total dissolved solids, is the most serious water quality problem in the Colorado River (El-Ashry, 1980). Cumulative damage from salinity to all water users is estimated to cost more than US\$113 million a year (in 1982 dollars) and that estimate is expected to more than double by 2010 if no controls are instituted (Kleinman and Brown, 1980). Salinity problems have worsened progressively as water resources have been developed. This trend will continue with future water development unless comprehensive, basin-wide water quality management schemes are implemented.

3. Alternatives to Dams and Interbasin Transfers

The Colorado River Basin is a good example to illustrate alternative and more efficient schemes for water management. In the past, increased water demand was satisfied by developing new water sources through the construction of large storage projects and interbasin transfers. However, environmental, engineering, and financial constraints are making traditional supply-side responses less tenable than they once were. The costs of transbasin diversions are becoming prohibitive - in the range of US\$8 per cubic metre for a planned project in Denver, Colorado - and the federal government is less willing to continue its generous subsidy. A new alliance of budget-cutters and environmentalists has focussed attention on the full costs of new dams, including the loss of free-flowing river reaches and the inundation of fertile lands and the habitat of fish and wildlife.

Proposals for interbasin transfers of water have met with the same resistance in recent years. Environmentalists point out the lost value of recreation sites and wildlife habitat as well as the potential for ecological disruption.

While the prospects for meeting projected water demand through new supply projects and importation look slim, options for reducing demand growth, increasing efficiency of use, and reallocating existing supplies appear promising.

3.1 Options for meeting urban water demand

Recent rapid rates of population growth in Western cities have now slowed somewhat, but forecasts call for continued increases in the absolute number of people living and working in cities dependent on Colorado River water. The costs, both for construction and for legal fees, of importing new water supplies have become prohibitive. The most viable option for these cities is to reduce and restructure demand, thus lowering per capita water use. The most effective demand-curtailement programme would contain elements of pricing, regulation and education. The "carrot and stick" approach to water management combines pricing water at its marginal cost to give consumers a clear idea of water scarcity while educating them on the need to reduce use and perhaps, rewarding them for water saved (El-Ashry and Gibbons, 1986).

Too often, water service agencies use an average cost pricing formula to just cover the total costs of water service. In many cases, however, a city's water supply curve exhibits

large discontinuities. For example, Tucson, Arizona, currently mines good quality groundwater costing approximately US\$0.04 per cubic metre. But as groundwater mining is phased out, the city will have to turn to Colorado River water, brought via the Central Arizona Project (CAP), which costs approximately US\$0.20 per cubic metre (excluding government subsidies) by the time it is delivered and treated. Ideally, the residents of Tucson, should pay the marginal costs of the new supplies from CAP and thus base their consumption patterns on full knowledge of the cost of the next source of water (El-Ashry and Gibbons, 1986).

Even with average cost pricing, the rate structure can make a difference. Traditionally, water is priced in declining block quantities: the more water a household uses, the less it costs. The odd result is that the heaviest users pay the lowest average water price. Cities still using average cost pricing need to invert this rate structure and charge more for each successive block in order to discourage wasteful water use.

From the standpoint of a region's overall water budget, separating household water use into indoor non-consumptive use and outdoor consumptive use is important. In most arid cities, municipal wastewater can be treated and used to irrigate public parks and golf courses. In some places, treated municipal effluent can be traded for higher-quality water from neighbouring agricultural communities. Households' consumptive uses, such as lawn watering and evaporative air conditioning, which cause the average monthly water consumption to more than double in the hot summer months, are the most important to curtail when supplies tighten. Since these are also the uses most responsive to water price, the demand-management potential of rational pricing should not be ignored.

Despite these potential gains, most water managers resist the idea of controlling water demand. They believe their mandate is to develop and supply water to meet anticipated demand, whatever it might be. However, in an age of economic scarcity, managers should note the success over the last 10 years of energy conservation and education programmes initiated by the electric utilities, institutions that once resisted demand management (for a discussion of electric demand-sided management see Edison Electric Institute and Electric Power Research Institute, 1984).

3.2 Options for agricultural water demand

Although municipal and industrial water needs are growing, water use in the Western United States continues to be dominated by irrigated agriculture. Much of the water supplied to irrigators originates in state or federal (U.S. Bureau of Reclamation) projects, heavily subsidized by tax-payers, so it is very inexpensive to the farmer. When combined with "use it or lose it" provisions in state water law and restrictions on use and on size and timing of return flows, the subsidies are a disincentive to conserving surface water. As long as water is cheap, it will be used inefficiently. Under present practices, irrigation efficiency is about 50 percent (El-Ashry, 1980). In addition, if farmers cannot consider the opportunity cost of retaining water for irrigation, because resale or leasing is prohibited, they have no reason to ensure that the economic return to water used for growing crops approaches that in alternative uses (Gardner, 1983).

Improved efficiency of irrigation water-use and reallocation of supplies among users are emerging as the most viable alternatives for meeting growing water demands in the arid Western states. They are less expensive and environmentally superior to large-scale structural measures. Increases in irrigation efficiency could release water for other uses without significantly decreasing agricultural output. For example, if 90 percent of a state's

water consumption is for irrigation, increasing efficiency by just 10 percent would double the amount of water available for urban residences and businesses.

Many technologies and techniques for improving irrigation efficiency exist, at varying costs. They may involve increases in the efficiency of irrigation water application and/or reductions in irrigation water losses from conveyance systems through seepage.

To increase water delivery efficiency and reduce seepage, canals, ditches and laterals can be lined with concrete, asphalt or plastic. Water measurement and flow control devices can be used to ensure that irrigators receive only the water required for evapotranspiration and to maintain a desirable salt balance. Delivery of excess water can also be eliminated through operational improvements in delivery schedules and call periods.

At the farm level, improved irrigation efficiency can be achieved through land levelling and modifications in crop management, such as special tillage practices and seedbed preparation. Improved irrigation efficiency can also be achieved through irrigation scheduling, flow measurements, and installation of water-efficient equipment, such as trickle irrigation systems. Automated, level-basin irrigation systems and lateral-moving or centre-pivot sprinkler systems can also be used for more efficient water use (El-Ashry and Gibbons, 1986).

One of the most obvious disincentives to improved irrigation efficiency, the low cost of water, needs to be redressed. Farmers pay nowhere near the full costs of the water they use to irrigate crops, many of which have low economic values. For example, the average water price currently paid by farmers in the Central Valley Project in California is US\$0.005 per cubic metre. The actual cost of this water, however, is US\$0.060 or more than 10 times the selling price. This translates into a subsidy of 91 percent of the total water costs (LeVeen and King, 1985).

Another disincentive to conserving water in irrigation is the lack of opportunity costs. This can be overcome by the establishment of a water market which would produce the necessary price signals and incentives for conservation. If a farmer stood to gain more from selling or leasing part or all of his water, that water would move to another use of higher value. The operation of a water market could provide the mobility and price signals needed to channel water supplies to the most valuable uses and to maximize total benefits. However, water-quality protection and preservation of streams and rivers for recreation and wildlife habitat are functions that could be compromised in a competitive market place for water. Expanded water markets could also lead to an increase in groundwater extraction in some areas, as people search to make profits on their surface rights (El-Ashry and Gibbons, 1986). But these problems are not insurmountable. For example, a good conjunctive use programme, in which surface supplies and groundwater are co-managed, could curb excess extraction.

Numerous legal and institutional barriers to water conservation and water markets need to be removed. Western state laws in the U.S. generally do not give irrigators the property rights to conserved or salvaged water. If a farmer increased irrigation efficiency, the quantity of water saved could not be sold or applied to new lands.

4. Summary and Conclusions

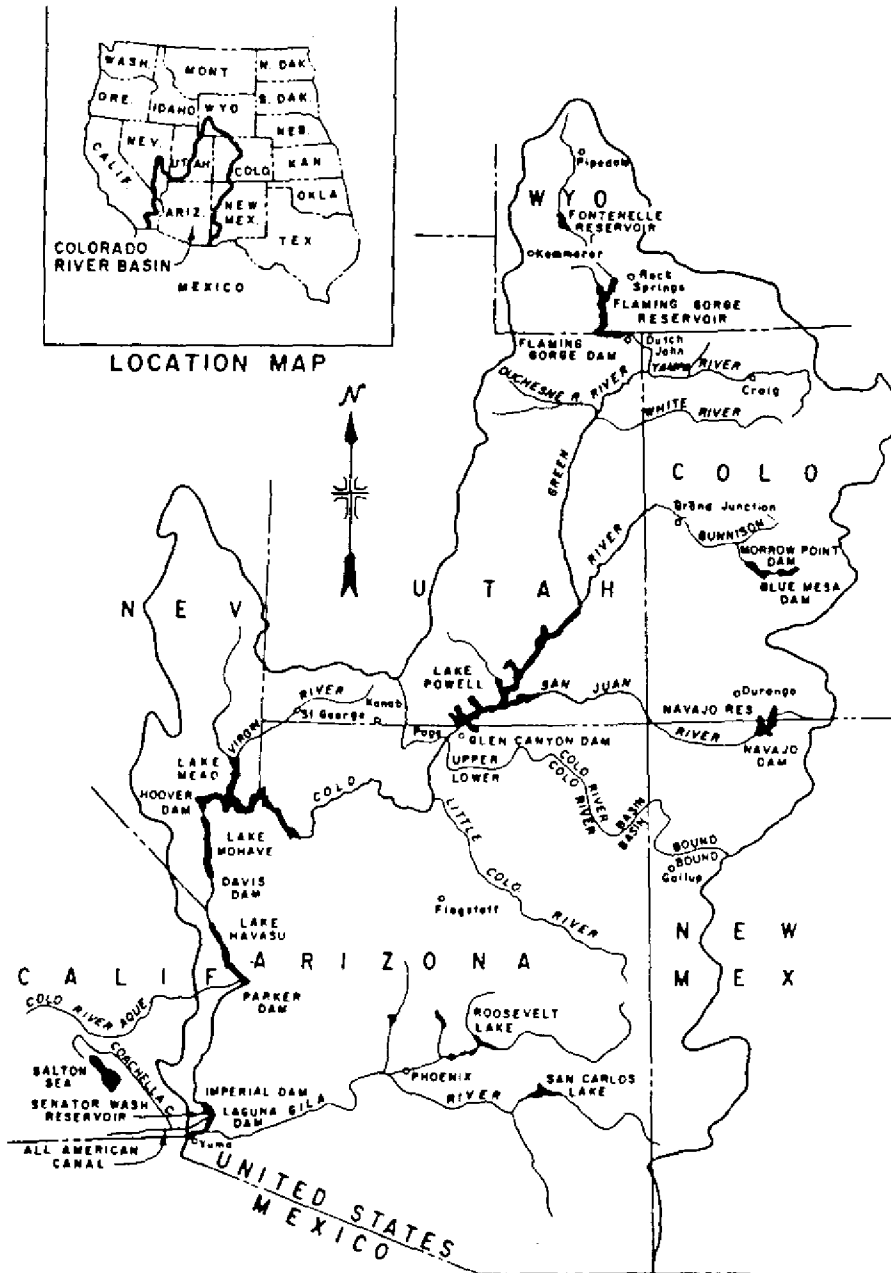
Like in many other river basins throughout the world, the impacts of individual water projects in the Colorado River Basin have been assessed separately and without concern for

the cumulative impacts on fish and wildlife habitat, the impacts of reduced streamflows and other physical modifications on water quality and aquatic life, or the impacts of irrigation return flows and streamflow depletions on salinity increases. There is now a need for comprehensive, basin-wide assessments of existing as well as proposed projects. The likelihood of closely related environmental effects should be considered a reason to group otherwise separate actions together for comprehensive analysis. Components of related flood control or other water resource projects should be grouped together for analysis of their cumulative effects in the common drainage system. Such comprehensive analysis would also help in identifying economically efficient and environmentally superior alternatives.

In the Western region of the United States, the time-honoured strategy of increasing water supplies through capital-intensive projects has reached its limits - financial, environmental and legal obstacles are overwhelming. Yet, improving water's productivity and mobility could enable the western states not merely to survive, but to thrive in this era of water shortages. For the most part, non-structural water management should replace structural water development and a "least-cost" accounting - incorporating all environmental and third party costs of any proposed project - should be at the heart of decisions on water resource management.

Specifically, cities should price water at its marginal cost, allowing individuals to decide whether to reduce their consumption or to pay the real cost of their additional usage. Higher summer rates could also help reduce the outdoor, consumptive portion of household water use and reduce peak water demand. In many cases, water service agencies will discover that "new" supplies found through water conservation are cheaper than supplies obtained through system expansion.

Active water markets could provide users, especially irrigators, with the opportunity costs needed to spur efficiency improvements and sales of excess water to other uses. Higher water-use efficiency in irrigated agriculture would free more water for present and future uses, and would also have many positive environmental consequences - saline and toxic irrigation return flows would be reduced and supplies would be available to augment instream flows for recreation or waste dilution.



UNITED STATES
 DEPARTMENT OF THE INTERIOR
 BUREAU OF RECLAMATION
 COLORADO RIVER BASIN

25 0 25 50 75 100 125 150
 SCALE OF MILES

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PAPER 15

ENVIRONMENTAL IMPACT ASSESSMENT OF SANTA ISABEL HYDROPOWER PROJECT

R.A. Braun

1. Abstract

The hydroelectric power station of Santa Isabel will be constructed on the Araguaia River, south of Belem in the state of Para, Brazil. The power produced is estimated to be 2 200 MW. It will supply mainly the Northern and Northeastern electricity network subsystems including the Great Carajas Mining Project. The development of this power station represents one of the main goals of PRODIAT's¹⁴ plan of action. This plan is based on the 3rd National Development Programme of 1980/1985 established by the federal government.

The objectives of PRODIAT are to encourage different development sectors which range from agriculture (including cattle farming), mining, industrial development, forest exploration, charcoal production, harvesting of forest products (for example, nuts and fruit), social development and the development of alternative sources of energy such as the Santa Isabel project. The whole area of the PRODIAT plan is 935 000 km².

The environmental aspects of this plan have been described and discussed in the report "Environmental Impact Assessment of PRODIAT Region", (Braun, R.A., 1984) in which all development sectors were analysed separately. The method applied in this study was simulation modelling of the environmental systems in the PRODIAT area. This method permitted the study of each sector and the identification of the major environmental impacts on natural, social and economic systems. The environmental impact assessment - (EIA) of Santa Isabel represents one chapter of the above-mentioned report. This paper was developed separately in order to consider environmental issues at the planning stage of the project. It has, as its basic guideline, the Federal Environment Agency's (SEMA) Normative Instructions for developing Environment Impact Reports (EIRs).

The general objective of this paper is to identify and assess the most important positive and negative impacts resulting from the construction and operation of Santa Isabel. Secondly, this paper seeks to stimulate the implementation of special programmes to reduce

¹⁴ PRODIAT - Project of Integrated Development of Araguaia-Tocantins River Basin. This project covers three different areas: The Amazon, the transition and the Savanna region. It involves the governments of Para, Maranhao, Mato Grosso and Goias states, and it was sponsored by the Ministry of the Interior and the Organization of American States (OAS). The main objectives are to develop the economic, social and spatial attributes of the region.

or prevent the negative impacts and to increase the positive impacts. The result of this procedure will link the main objectives of the National Environment Policy with the policy of the federal government on economic and social growth.

2. Introduction

The hydroelectric power station of Santa Isabel is one of the major developments in the continuing exploitation of the hydroelectric potential of the lower Araguaia-Tocantins river system. The plan of PRODIAT estimates that the construction of Santa Isabel will take place in the 1980's and the operation phase is planned for the decade beginning in 1990. The company responsible for this project is Eletronorte¹⁵. The main objectives of Santa Isabel are to serve the increasing market for electricity in the Northern and Northeastern regions of Brazil. The development of this project will also provide sufficient energy for the Great Carajas Project. This project is the major mining investment programme in Brazil, involving an expenditure of US\$725 x 10GM. It will produce iron, copper and manganese for national and international markets. Also, Santa Isabel will contribute to a significant regulation of water flow thus aiding the development of the second stage of the Tucuruí Hydroelectric Power Station.

The Brazilian Ports Agency - Portobras - has selected, in the PRODIAT plan, the Araguaia river as the main axis for river transport in central Brazil. It will provide economic transportation for products and local people between production and consumption areas. Locks will be built for navigation along almost the entire length of the river, from Barra do Garça in Mato Grosso State to Belem, capital of Para State, a distance of approximately 1 700 km. The river transport systems integrate with main motorways. On the other hand, the development of this project may lead to major environmental problems which have to be taken into account at the planning stage.

Based on the Federal Environmental Agency's (SEMA) normative instructions for preparing Environment Impact Reports, this work was carried out to systematically identify and assess the most important environmental impacts. This procedure allowed formulation of general recommendations for the project before the construction of the dam and after filling of the reservoir. These recommendations are related mainly to social and economic factors, and, in addition, to ecological issues within the area of reservoir. This work utilised information on Santa Isabel produced by Engevix/Eletronorte and the PRODIAT plan of action.

3. Location of the Project

The project will be developed 523 km south of Belem in Para State approximately 30 km from Xambioa municipal district and the village of Sao Geraldo do Araguaí (6° 2'S x 48° 4'W).

¹⁵ Brazilian Power Company responsible for Northern region of Brazil. This company is responsible also for the construction and operation of the Tucuruí Hydroelectric power station

4. Background Information on the Project

4.1 Hydrological data

The Araguaia river is in the Serra dos Caiapos mountains in the State of Mato Grosso do Sul. It forms a natural boundary between Mato Grosso and Goias States, as well as Para and Maranhao States. The total length of the Araguaia is approximately 1 900 km from its source to the City of Sao Joao do Araguaia where it meets the Tocantins river.

The mean annual streamflow for the period 1931-1981 at Santa Isabel stream gauging station was 5 443 m³s.⁻¹. the equivalent depth of runoff is 462 mm (area 372 000 km²) and the specific flow is 14.63 lkm⁻² (PRODIAT, 1982).

4.2 Technical information

Reservoir:

- maximum area under normal operation (km ²)	3 840
- minimum area under normal operation (km ²)	1 840
- volume of water (Mm ³)	25 200
- total accumulation volume (Mm ³)	44 200
- total length (km)	440
- maximum width (km)	35
- depth (m)	153
- total flooded area with depth of 153 m (km ²)	2 840
- expropriation of land (km ²)	4 100
- power capacity (MW)	2 200

Dam Discharge:

- maximum discharge per floodgate (m ³ s ⁻¹)	3 677
- total discharge (m ³ s ⁻¹)	44 120

Spillway Discharge:

- maximum discharge per floodgate (m ³ s ⁻¹)	3 470
- total discharge (m ³ s ⁻¹)	13 880
- dam height (m)	157
- dam width (m)	845

(Engevix Electronorte 1984)

4.3 Power lines

The transportation of energy will require two simple circuit lines with capacity of 138 kV each. The total length will be approximately 127 km. (118 km in Goias State and 9 km in Maranhao State). The power lines will cross savanna and forest regions, both of which have slightly undulating topography.

4.4 Infrastructure required for the project

The feasibility studies indicate the need to develop basic infrastructures including the construction of interconnecting roads between main motorways and the dam construction

site, and the construction of two settlements for workers and dependants with all necessary public services required for the expected population. The combined area of both settlements is approximately 300 ha.

5. Description of the Project Area

5.1 Natural system

The dam is to be located within the Araguaia hydrologic basin (sub-basin of Araguaia-Tocantins Rivers). The reservoir will flood 2 840 km² of rain forest (60%), transition and savanna regions (40%).

Climate

The climate will be described according to the Koppen classification. In the rain forest the climate is Am with 3 months of dry season and annual precipitation up to 2 000 mm. The annual average temperature is 30°C. In the savanna and transition regions the climate is Aw with 4 to 5 months of dry season and an average annual precipitation of 1 500 mm.

Geology and geomorphology

Santa Isabel will be constructed on the Brazilian central shield formed of well consolidated sedimentary rocks. The geomorphic features can be classified, basically as tropical zone with extensive plain development (Snead, R.E., 1980).

Soil

The character of the soils in the area to be flooded can be linked with their potential for agricultural development. Based on a PRODIAT soil survey (Braun, E.H.G., 1980) and agricultural development maps it was possible to identify four different types of agricultural land use areas that will be flooded by the reservoir:

1. Lands with no aptitude for agriculture, only for fauna and flora preservation and recreational areas (15 percent)
2. Land not totally suitable for agriculture, only for short or long cycle rice cultivation (5 percent).
3. Land restricted to management A and B¹⁶ (60 percent)
4. Land suitable for any type of management (10 percent).

Vegetation

¹⁶ A - Agricultural development with low technology needs: research, management and conservation, implementation of animal traction, low-cost management
B - Agricultural development with medium technological needs: research, management and conservation, implementation of animal and human labour, medium-cost management

The vegetation identified in the area to be flooded is based on the vegetation map (PRODIAT 1981/84). These are generally of three different types corresponding to rain forest, transition and savanna. The specimens that occur in the reservoir area (rain forest) are hevea, rubber, palms, castanhas, lianas, mohogany, virola, peroba, cherry wood, sucupira and others. In the transition and savanna region, there are forest galleries along river banks and in some cases tropical grasslands mixed with typical savanna species. The best areas for forestry are situated on either side of the Araguaia river, especially between the latitudes 6° and 8° S and longitudes 48° and 49.5° W (PRODIAT, 1983).

Fauna

The fauna in the rain forest area is very diversified due to the different types of ecosystems. It can range from aquatic to terrestrial fauna in a very complex food chain system. The local population including local indigenous Amerindian groups depend on fauna living in the forest with special emphasis on ichthy fauna near the Igapo.¹⁷

In the transition and savanna region, the fauna is not as diversified as in the rain forest. Some examples of transition/savanna fauna are the Guara Wolf, Tatu, Paca (spotted cavy), birds of prey, monkeys and various species of reptiles and insects. The representative ichthyofauna species eaten by the local people are surubim, dourado, piau and other local specimens.

5.2 Social and economic systems

The area surrounding the dam has a very low density of population (average 5-6 inhabitants km⁻²) (PRODIAT, 1982) due basically to its remoteness from main urban centres and because of difficulties of access.

Space occupation

The population density in the area has increased between the 1960's and the 1980's. The average rate of increase in 1960 was approximately 26 percent, increasing to 60 percent in 1980. The growing population has affected the employment rate which has grown by 6.5 percent per year (PRODIAT, 1984).

Population

The population affected by flooding, according to the 1980 census of the Brazilian Geography Institute (IBGE), will be 25 080 inhabitants. It is estimated that by 1993 the population will have increased to 48 700 inhabitants (PRODIAT, 1984).

Urban areas affected by flooding

The area to be flooded is estimated at 2 840 km² and this will affect many villages and towns near the Araguaia river. In Goias State six urban areas will be flooded: Ananas, Xambioa, Araguaina, Arapoema, Colmeia, Couto de Magalhaes, and Aracuacema. In Para State five urban areas will be affected: Sao Joao do Araguaia, Xinguara, Rio Maria, Conceicao do Araguaia and Santana do Araguaia (Engevix/Electronorte, 1984).

¹⁷ A forest bordering a river which is subject to fluctuations of water level such that for months the trees are partly inundated.

Indigenous groups

The reservoir will affect the Karaja native population estimated at 100 inhabitants. They will lose approximately 3 537 ha of the native Zambia Park but alternative land has been provided for the Karaja community on which to resettle (Engevix/Electroborte, 1984).

Land use

The area of influence of the reservoir has a very good potential for cattle production. Almost 50 percent of this area can be intensively utilized for this activity. The rest of the area could be divided into semi-intensive and intensive areas for cattle, and there is also a potential for antelope breeding (PRODIAT, 1982). Although these potential areas will be flooded, they represent a very small portion of the total area estimated by PRODIAT's plan of action for this sector. The area at the moment carries few cattle and only offers subsistence agriculture. No relevant agricultural project has been proposed by PRODIAT for this area (PRODIAT, 1982). although there are good agriculture lands in the region.

Harvesting of forest products

Harvesting forest products such as babacu, Para chesnuts, latex, dende and some others represents a very intensive activity in the rain forest area and in the absence of proper management this leads to ecological problems.

Timber and charcoal exploitation

The exploitation of timber occurs mainly in the rain forest and in the transition zone and represents an important activity in these two regions. Deforestation is occurring in parts as a result of charcoal production, not without serious ecological repercussions (PRODIAT, 1984).

6. Identification of Environmental Impacts

6.1 Methodological approach

The methodology applied in this work used both the matrix and network approaches. These two methods were applied in order to establish an integrated process of identification of the most important impacts, followed by the demonstration of the links between social, economic and ecological factors.

Matrix approach

The two-dimensional interaction matrix was designed to relate the main activities of the Santa Isabel construction and operation phases with the major environmental impacts (Table 1). The impacts listed on the matrix represent, on the one hand, the effects of the project on the major objectives of the PRODIAT plan of action, and on the other hand the risk of negative environmental consequences due to the development of the project. The reservoir filling stage, for example, represents an activity that will positively affect the development of river transportation and employment, but will negatively affect the ichthyofauna and biomass decomposition.

The network method was developed to demonstrate, in a systematic way, the major secondary consequences of the most important impacts identified in the matrix. This method is very useful for showing the inputs and outputs of each impact. One impact may generate two or more secondary impacts (Figures 1 and 2).

Figure 15.1

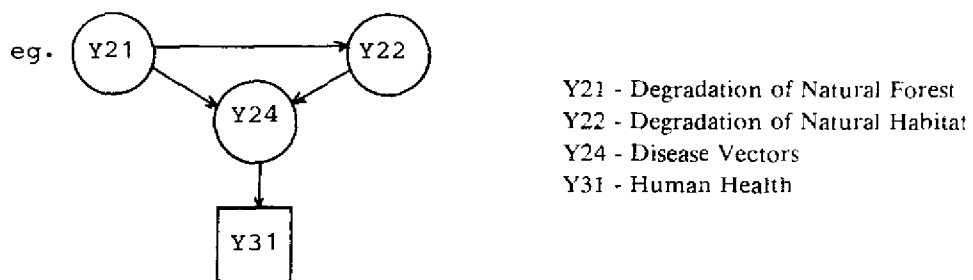


Table 1

**MATRIX OF ENVIRONMENT IMPACTS:
SARAF ISRAEL HYDRO-ELECTRIC
POWER STATION**

ENVIRONMENTAL IMPACTS			PROJECT ACTIONS					
			DEFORESTATION	LAND MOVEMENTS	CONSTRUCTION OF DAM	NORMAL OPERATION	CONSTRUCTION OF POWER LINES	RESERVOIR FILLING
E	Y1	Timber Exploitation	1	1		1	1	
S-E	Y2	Development of River Transport					2	2
E	Y3	Energy for Industrial Development				2		2
E	Y4	Energy for Mining Development				2		2
S-E	Y5	Development of Direct and Indirect Employment	1	1	2	1	2	2
E	Y6	Development of Charcoal Production	1			1		
S	Y7	Development of Public Services and Urban Equipments		1	2	1		2
S	Y8	Housing Development	1	1	2			
S-E	Y9	Absorption of man power from other regions	1	1	2	1	1	
S	Y10	Resettlement of population	1	1	2		2	1
S	Y11	Energy for regional consumption centres				2		2
S	Y12	Preservation of Historical and Cultural Sites/Artefacts		1	2	1		
E	Y13	Increase circulation of Products (economic activity)					2	2
N	Y14	Rescue					2	2
S	Y15	Development of Recreational Areas					1	2
N	Y16	Acidification of water					1	1
N	Y17	Low level of DO (dissolved Oxygen)					1	2
N	Y18	Soil Erosion	2	1		1	2	1
N	Y19	Turbidity of water (Siltation)					1	1
N	Y20	Ground water level					1	
N	Y21	Begradation of Natural Forest	1		1		2	
N	Y22	Degradation of Natural Habitat	1		1		2	
N	Y23	Degradation of Ichthyofauna			1		2	1
N	Y24	Disease Vectors	1			1	1	2
N	Y25	Decomposition of Biomass					2	2
N	Y26	Migration Barrier for Ichthyofauna			2		1	
N	Y27	Change of climate (micro and macro)					1	1
N	Y28	Creation of New Ecosystems					1	1
N	Y29	Flooding of Towns and Villages					1	
S	Y30	Expropriation of Population			2	1	1	
S	Y31	Human Health					1	2
S	Y32	Cultural Impact	1		1	1	2	1
E	Y33	Loss of Potential Agriculture and cattle Farming Lands					2	
E	Y34	Loss of Timber					1	
E	Y35	Loss of Motorways					1	

Positive (+) Impacts
Negative (-) Impacts

Legend
 1 - Important Impact
 2 - Very Important Impact
 N - Natural
 S - Social
 E - Economic

The network chart is very useful for identifying where to maximize the positive impacts and where to minimize the negative ones. In theory this is possible by reducing or increasing the quantity and/or quality of inputs (energy, products, raw material, equipment, water, air, manpower and others). These inputs will consequently affect the quantity and quality of the outputs (discharges, pollutants, noise, vibration, products, services, resources and others).

6.2 Number of impacts identified:

The matrix approach allowed the identification of the following major positive and negative environmental impacts:

POSITIVE IMPACTS

- Development of river transportation
- Electric energy for industrial development
- Electric energy for mining development
- Development of direct and indirect employment
- Development of public services and urban infrastructures
- Housing development
- Resettlement of population
- Electric energy for regional consumption centres
- Increased circulation of products
- Recovery and preservation of historical, cultural and ecological inheritance

NEGATIVE IMPACTS

- Low levels of OD
- Soil erosion
- Water acidification
- Degradation of natural forest
- Degradation of natural habitat
- Degradation of ichthyofauna
- Disease vectors
- Decomposition of biomass
- Migration barrier
- Expropriation of land
- Human health
- Economic impact

Total number of impacts identified	94
Total number of positive impacts	46
Total number of important positive impacts	23
Total number of very important positive impacts	23
Total number of negative impacts	48
Total number of important negative impacts	35
Total number of very important negative impacts	13

6.3 Comments on the most important environmental impacts

6.3.1 Positive impacts

According to the Feasibility Studies (Engevix/Electronorte, 1984) the Santa Isabel development will result mainly in social and economic benefits. These benefits will not only be reflected at local level, but also at regional and national levels.

Power generation

The generation of 2 200 MW of electric power will supply part of the Great Carajas project. It will also serve industrial plants situated in the major cities in the North and Northeastern regions. The energy produced will also stimulate the development of new industrial plants.

River transport

One of the major benefits is the development of river transport in the Araguaia-Tocantins area. This will permit the transportation of products and raw materials between production and consumption areas. The costs for this type of transportation will be much lower than that of the road transport.

Employment

The development of the project will involve the participation of approximately 22 000 inhabitants (economically active population) (Engevix/Electronorte, 1984). This will positively affect the level of direct and indirect employment in the region. The construction of the dam will absorb manpower from other regions in Brazil.

Development of urban units

Another major objective is to develop two settlements for the work force and their dependants engaged on the project during the construction and operation phases. These settlements will have the basic urban infrastructures and services and include recreational sites.

Resettlement of population

The population affected by flooding will be resettled in areas adjacent to the reservoir and new townships. The Karajas native population from Xambioa Park will be resettled in a special area.

Preservation of ecological and cultural heritage

There will be a project to rescue endemic fauna. This programme will be carried out during and after reservoir filling by the Amazon Research Institute (INPA) and the Goeldi Museum. There will be also a project to rescue and preserve endangered cultural and historical remains with special reference to archaeological sites.

6.3.2 Negative impacts

Biomass Decomposition

The flooding of natural forest will lead to decomposition of submerged biomass. This process, depending on quantity, will negatively affect the water quality (acidification) with the formation of hydrogen sulphide and methane gas. It will also affect the turbines of the power station. The deterioration of water quality, particularly the low levels of dissolved oxygen, will have a negative impact on the micro-organisms and ichthyofauna upon which some people depend for a living.

Disease vectors

During and after reservoir filling there is a strong probability that health problems will arise. The impounded water, aquatic plants and semi-submerged trees represent an ideal habitat and feeding source for malaria vectors and the snail, host of schistosomiasis (bilharzia). Increases in these vector populations may cause serious health problems in the settlements neighbouring the reservoir.

Ecological impact

The reservoir will create a totally new ecological system for living organisms which will have to adapt themselves to the new conditions. This is likely to affect the basic food chain links. The main changes will be in aquatic, physical and chemical parameters with resulting ecological changes amongst aquatic communities.

Migration barrier

The dam construction represents a physical barrier for seasonal fish migration and will affect spawning. Communities which depend on fish as basic food, will be affected.

Erosion

Erosion of the river bed downstream of the dam and of the reservoir banks together with soil erosion due to human activities upstream may increase sediment loads. This may lead to high turbidity, low primary productivity and low fish yields. Sedimentation will reduce the life span of the reservoir.

Deforestation

The deforestation of natural forest will affect the natural habitats of endemic species, leading to a disorganized dispersion to adjacent areas. Deforestation may lead also to soil erosion.

Social impacts

Social impacts are mainly linked with the expropriation of land, loss of houses and jobs due to reservoir filling. The traditional customs of the population may be altered with probably harmful psychological consequences as a result of resettlement. This effect will be much more radical on the Karajas community, mainly because of their strong cultural identity.

Economic impacts

The negative economic impacts are those related to the loss of potential land agricultural and cattle land, the loss of 4.6 m³ha⁻¹ of first and second class timber and the loss of highways.

7. Recommendations

Recommendations are twofold: *before* the construction, of and *after* filling of the reservoir.

A multidisciplinary team should be formed to pursue social, economic and ecological studies.

Before construction of the dam:

1. Develop social and economic programmes
 - 1.1 Public involvement
 - 1.2 Study different alternative sites for the urban units, including suitable environmental sites for the Karajas native community
 - 1.3 Develop plans to employ manpower from the expropriated areas and flooded towns and villages
 - 1.4 Develop land use projects in resettlement areas
 - 1.5 Develop plans to re-employ manpower after the construction of the dam
 - 1.6 Develop studies for providing electric energy in rural areas
 - 1.7 Develop management and maintenance programmes for the urban units
 - 1.8 Develop fishery projects for reservoir
 - 1.9 Develop traffic planning for river transportation
 - 1.10 Develop environmental education programmes linked with preserved ecological and cultural areas and sites

2.Environmental studies

- 2.1 Climatological studies and soil surveys
- 2.2 Fauna and flora (ichthyofauna survey, quantification and survey of flooded woodlands, survey of aquatic plants and flora identification)
- 2.3 Ecosystems (fishery potential, biomass degradation, endemic diseases and water quality)
- 2.4 Preservation of area for rescued fauna
- 2.5 Ecological research programmes in cooperation with local universities and institutions

After development of the project:

1. Sow grass on bare of reservoir banks to prevent soil erosion.
2. Afforestation of slopes with fast growing trees to rehabilitate deforestation areas
3. Stabilization of river channels by means of a series of weirs to reduce reservoir sedimentation
4. Monitor water quality (upstream, reservoir and downstream)
5. Control human activities upstream to prevent deforestation and water pollution
6. Control of malarial by biological and chemical means
7. Control of schistosomiasis by melescosiding focal points and biological control
8. Health education for local population

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Note: Based on recent information from Electrobras - Brazilian Power Company - the development of Santa Isabel will not be carried out before 1995. According to the recent Resolution from Conama - National Environment Council - on the implementation of environmental impact studies, an environmental impact assessment of Santa Isabel will be undertaken. The guideline for this study will be the Manual for Environmental Studies prepared by Electrobras.

PAPER 16

IMPACT OF WATER RESOURCES DEVELOPMENT IN THE UMBELUZI RIVER BASIN

Alvaro Carmo Vaz¹⁷

1. The Umbeluzi River Basin

The Umbeluzi River Basin is a relatively small watershed with a drainage area of about 5 600 km², shared between Mozambique (2 300 km²) and Swaziland (3 300 km²) (Figure 1). The river has its source in Swaziland, and has two main branches, the Black Umbeluzi and the White Umbeluzi, which merge some 35 km before the border with Mozambique to form the Umbeluzi River. The main branch of the river, the Black Umbeluzi, rises near the city of Mbabane, the capital of Swaziland, at an elevation of approximately 1 500 m and flows eastward. At the Mozambican border, the altitude is only 150 m. The average annual flow is of 393 Mm³ at the border (Goa Station) and 439 Mm³ at the mouth in Mozambique.

The Umbeluzi basin assumes a particular importance for the two countries because it is the main source of drinking water for both capital cities, Maputo and Mbabane. Mbabane has about 100 000 inhabitants, while Maputo has reached one million. Besides that, the Umbeluzi basin has a good potential for irrigated agriculture, important not only for its economic value but also as a means of fighting against the increasing migration from rural areas to the cities. This has strained the naturally available water resources and has led to the elaboration and partial implementation of plans to make full use of the water mainly through important hydraulic structures to regulate streamflows.

2. Past Developments and Problems in the Basin

The city of Mbabane was being supplied with about 8 650 m³/day in 1980 and the withdrawal was increasing at a rate of 1 300 m³/day/year. The total abstraction of water for this purpose was relatively low and no pollution problems were created in the river as wastewater was not returned.

The city of Maputo began having problems of scarcity of water in the early '70s, especially during the dry season when the river had very low flows. The system pumps water from the river at an intake some 30 km distant from Maputo at a rate of about 75 000 m³/day. In the Mozambican part of the basin, some medium-scale irrigation schemes existed, mainly for orchards, totalling about 3 000 ha. At that time, plans were made to build an earth dam to allow for water storage and regulation, not only for the urban supply system but also to expand the irrigated area to about 10 000 ha.

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Also in 1970/71 a study prepared in Swaziland proposed the construction of a dam on the Black Umbeluzi to create a new irrigated area of 10 333 ha for sugar cane. To obtain the external financing needed to implement the project, Swaziland had to sign an agreement with Mozambique on the division of natural flows. This was done in 1976, one year after Mozambique's Independence. The essence of the agreement is that Mozambique will receive 40 percent of the virgin flow from Swaziland, the flow being the sum of the measured discharges at the stations GS3 and GS10 (Figure 1), which account for one third of the Swaziland part of the basin. Although not explicitly stated in the agreement, it was accepted later that the control should be made on a daily basis. The agreement also included exchange of hydrologic information and flood warnings.

M'njoli dam in Swaziland was completed in 1979 with a live capacity of 130 Mm³ with a surcharge storing during floods of about 100 Mm³. At the same time, 4 000 ha of irrigated land were put into operation, increasing to about 9 000 ha by the end of 1983. The large amounts of water used by the irrigation scheme in Swaziland decreased very significantly the flows in Mozambique, especially during the extreme drought of 1981-83. Figure 2 presents the monthly values at the border during this period in comparison with the monthly averages. The situation of the water supply to Maputo in 1983 was so critical that Swaziland was asked to deliver more than the amount of water established in the agreement. Harsh restrictions were imposed on domestic and industrial consumers in Maputo and, during a certain period, irrigation was totally forbidden, a situation that brought enormous economic losses. Damages suffered by the orchards were not even recovered in the following years.

The feasibility study for Pequenos Libombos reservoir was made in 1979-80. It considered water supply to Maputo with a fixed value of 170 000 m³/day, corresponding to the projections for the year 1991, as well as a number of irrigation variants. The solution that was adopted included an additional irrigation area of about 13 000 ha, most of it located upstream of the dam, the water being pumped directly from the reservoir (MONENCO, 1981). The total capacity of the dam was 385 Mm³, with a maximum flooded area of 38 km², a maximum height of 46 m and a crest length of 1 540 m.

Construction of Pequenos Libombos dam started in 1983 and is due to finish at the end of 1986. In 1987, a first block of 3 000 ha will be constructed.

Before 1984, the Umbeluzi basin had suffered only minor floods with the exception of the big 1918 flood. But at the end of January 1984, when the drought effects were still present, a major flood occurred, caused by the tropical depression "Domoina". The movement of this cyclone produced intense rainfall in the whole basin. The amount of precipitation recorded during the flood in a number of stations was almost equal to, and in some cases exceeded, the annual average (Kranendonck and Vaz, 1984). Both countries suffered severe damage. In Swaziland, the flood destroyed many bridges and parts of roads as well as the emergency spillway of M'njoli dam. Sediment transport was very intense with strong erosion and sedimentation effects, such that even the weir of the important GS3 station became completely silted. In Mozambique there were 20 deaths. Roads were cut, power lines were broken, irrigation areas were damaged. The direct losses were estimated as being more than twenty million US dollars. Some areas were lost for agriculture after being covered by thick layers of coarse sand. At Pequenos Libombos construction site, the rise of water levels was very fast (from a few cubic metres per second to 5 700 m³ s⁻¹ in 20 hours (Figure 3), but even so appropriate measures were taken and no irreparable damage occurred. One of the worst consequences of "Domoina", besides the deaths, was the flooding of the Maputo water treatment plant that left the city without a piped supply during two weeks.

3. The Need to Regulate Streamflows

Given the needs imposed by the urban water supply to the cities of Maputo and Mbabane and by the development of irrigation, it was evident that storage reservoirs had to be built, considering the large periods of time during which available natural flows would be smaller than the amounts needed.

Figures 4 and 5 illustrate clearly this situation. Figure 5 represents 10 years of historical flows at GS3 station. This is compared with the water needed for the irrigation of 13 000 ha or for 9 000 ha and it can be seen that even the irrigation of the smaller area does not attain an acceptable level of reliability. Figure 4 presents a similar analysis with the natural flows at Goba station in Mozambique, considering a supply to Maputo of 170 000 m³/day and irrigation areas of 16 000 ha and 4 000 ha. Also in this case, the reliability of irrigation would be much less than usually accepted. It must be noted that in the real situation the flows should be decreased by the amounts corresponding to consumptive use in Swaziland.

4. The Impacts of Water Development

4.1 *Impacts in Swaziland*

Not enough information is available in Mozambique to evaluate the impacts of the water development that has taken place in Swaziland with the construction of M'njoil dam and the expansion of irrigated areas. From the economic point of view, the results seem to be positive: Swaziland, which was dependent for irrigation on a water transfer from the Komati basin located mostly in South Africa, could assure its own supply not only for the existing irrigated areas but also for new ones, allowing the introduction of a cash crop such as sugar cane.

4.2 *Positive impacts in Mozambique*

In Mozambique, the construction and operation of Pequenos Libombos reservoir together with the construction of a new irrigated area of about 13 000 ha will have very positive impacts described in the following paragraphs.

4.2.1 *Water supply for Maputo*

MONENCO 1981 presented the results of a simple simulation study of the operation of Pequenos Libombos reservoir, done on a monthly basis considering the operation of M'njoli reservoir, the abstractions in Swaziland and the rules defined by the agreement between the two countries. The study considered full development of irrigation in Swaziland and in Mozambique and a growing demand of water for the cities of Mbabane and Maputo. The reliability, defined as the percentage of time full demand is satisfied, was 99 percent for water supply and 80 percent for irrigation.

The guarantee with the Pequenos Libombos reservoir of a regular source of water supply to Maputo will be a complement to three important components: an expansion of the treatment plant which will double its capacity; a new trunk main linking the treatment plant with the storage tanks near Maputo; and a revision and upgrading of the Maputo distribution system.

The normalization of the water supply to Maputo represents the satisfaction of a fundamental basic need of the population which was being offered a very deficient service during the last years. This will have a positive impact on health, allowing for the improvement of hygienic conditions at residences and other places and reducing the possibilities of very common children's diseases like diarrhea and epidemics such as cholera that appeared in Maputo in the period 1982-83.

4.2.2 Food supply

Maputo is undisputedly the biggest food consuming centre of the country. Until 1980, most of the food supply came not only from neighbouring areas in Maputo province but also from regions located in the provinces of Gaza and Inhambane, 300 to 500 km distant from Maputo city. The situation changed drastically in the last five years: the severe drought that affected the country and mainly the southern region disrupted the agricultural sector, forcing thousands of peasants to leave their lands; this was compounded by the security problems which made more difficult the transport of agricultural production over long distances by road or railways. The development of irrigation in the Umbeluzi basin will provide a safe and close source for a significant part of its food supply.

4.2.3 Creation of new employment opportunities

The drought and the security problems increased tremendously the population growth in the city of Maputo that attained more than 6 percent while the average in the country is around 3 percent. This has created enormous difficulties in the city where the existing infrastructures cannot cope with this growth rate. The situation is made worse by a stagnant economy whose industrial and construction sectors have problems to maintain the existing level of employment. The consequent high rate of unemployment has led to an increase of social problems like theft, black market and so on. The 1980 population census indicated that only 30 percent is considered active, with 10 percent engaged in to agriculture. The average age of the city population is between 20 and 25.

The development of the irrigation schemes in the Umbeluzi basin is expected to create directly about 15 000 new jobs, corresponding to a total of 75 000 people, number that far exceeds the locally available labour and creating a possibility of employment for the unemployed in Maputo. This will also help to decrease migration to the city and an alternative to migration to the neighbouring countries. A large number of jobs will also be created the associated food industries as well as in other sectors such as transport, trade, services and so on.

4.2.4 Flood control

Flood control was not a priority during the initial stages of planning and design of Pequenos Libombos reservoir, but the "Domoina" flood in 1984 drew attention to this problem. The operating rules considered for the reservoir are being revised to obtain a large reduction of the downstream peak discharge. This means that, during the rainy season (October-March), the reservoir will be kept below normal level to provide storage capacity for the incoming flood. There is always the possibility of a dry year leaving the reservoir with less water than would be available if flood storage was not provided, with a certain decrease of the reliability of supply for the irrigation areas. A preliminary analysis made by ODKW (1986) showed that this would not be the case in the next few years while irrigation is not yet totally developed, but when all irrigated areas are in operation a balance should be sought between flood attenuation and reliability of irrigation. A routing of the

"Domoina" flood hydrograph through the reservoir (ODKW 1986) shows a reduction of the peak discharge from $5\,700\text{ m}^3\text{ s}^{-1}$ to $2\,600\text{ m}^3\text{ s}^{-1}$. It was indicated also that, in three years out of four, flood discharge could be kept below $100\text{ m}^3\text{ s}^{-1}$.

4.2.5 Other positive impacts: small hydroelectric plant, fisheries, recreation

All development in the Mozambican part of the Umbeluzi basin was centred on the urban water supply and irrigation, other uses having minor impacts being treated as by-products of the development.

The amount of energy that can be produced at the Pequenos Libombos dam, with partial development (4 000 ha) of irrigation upstream of the reservoir, is relatively small, being estimated at 7.4Gwh with 4.3Gwh of firm energy for an installed power capacity of 4MW produced by two Kaplan turbines (Norconsult, 1984). The energy would result from water being discharged for the urban water supply and the irrigated areas downstream of the dam. Studies are still under way to determine the economic and financial feasibility of the hydropower station.

The development of fisheries in man-made lakes is making a slow start in Mozambique, the first efforts being concentrated in the Cabora Bassa reservoir. Other large reservoirs like Massingir and Chicamba are receiving minor attention in relation to this problem, basically due to the lack of qualified personnel to undertake studies. The same is happening with the new reservoirs like Pequenos Libombos. A rough estimate of the fisheries potential at this reservoir was made by Robelus (1984a) based on a morpho-edaphic parameter. He arrived at an annual value of between 250 and 300 t which, even if this is relatively low, could have a positive effect on the diet of the peasants.

No quantitative study has been undertaken in relation to the potential of the Pequenos Libombos reservoir for recreation. It seems logical with the beauty of the scenery, the proximity of Maputo and the good road link, that it will become an appreciated resort as soon as a minimum investment in touristic infrastructure is made. The study of ODKW (1986) shows that it is possible to maintain a high and more or less constant water level in the lake during long periods.

4.3 Adverse impacts in Mozambique

Water developments in the Mozambican part of the Umbeluzi basin will give rise to a number of problems that will have an adverse impact on the socio-economic development of the region. These adverse impacts have not been closely studied and analysed and so the information is not very precise.

4.3.1 Water quality in the reservoir

The impoundment of water always affects its quality. There are a number of reasons for this, among which (Thanh, 1985):

- a much increased "detention time", providing opportunity for slow reactions to come to completion;
- thermal stratification that creates a number of distinct layers within the water body, which are chemically different from each other;
- increase of the phosphorous and nitrogen content of the water.

Thermal stratification has a direct influence on the distribution of dissolved oxygen with the lower stratum, the hypolimnion, easily becoming deoxygenated. Water released from the hypolimnion will generally be rich in dissolved nutrients, and include heavy metals which can have toxic effects on the downstream biota. The lack of oxygen and presence of hydrogen sulphide will also damage fish life until the river water reoxygenates itself.

In the case of the Pequenos Libombos reservoir, water quality is a very important problem considering that domestic water supply is the main use of the impounded water. Some measurements of water quality indicated a significant increase of water mineralization in the Umbeluzi river since the development of irrigation in Swaziland (Suschka, 1984). This situation can be made worse by the irrigation in the areas immediately upstream of the Pequenos Libombos reservoir, some of which are erosion prone. A study made by the Ministry of Health (Robelus, 1984b) came to a preliminary conclusion that the reservoir would not become eutrophic in a reasonable span of time but drew attention to the need of an effective watershed management and control of the rate of nutrients being drained to the reservoir. Favourable aspects in terms of water quality and control of eutrophication in the reservoir are the limited retention time of the reservoir and the outlet conduits located at different levels which allow discharge of the hypolimnion of water from time to time, providing for additional mixing of water in the reservoir. The conduits of water intake at different levels also allow choosing water of better quality to be discharged for the urban water supply.

Aquatic weeds like the water hyacinth can be a major hindrance in reservoirs and irrigation canals. In reservoirs they can cover a large area, blocking out sunlight, damaging fish life and, through death and decay, accelerating the deoxygenation of the hypolimnion. They also increase tremendously the evaporation from the lake. In irrigation canals they decrease the cross-section and increase evaporation. Fortunately, till now there is no strong presence of aquatic weeds in the Umbeluzi basin and they have not appeared in M'njoli reservoir.

4.3.2 Health problems

New storage reservoirs and irrigated areas may favour the expansion of certain vector-borne diseases like malaria and schistosomiasis. Malaria is transmitted through the *Anopheles* mosquito and schistosomiasis through a snail.

Robelus (1984b) made a preliminary evaluation of the potential for growth in mosquito population and, based on a "marsh potential index", he found that there was not a great danger. A measure to be taken is to avoid new human settlements near the shores of the lake. Also, a small weekly fluctuation of reservoir level could be included in the operation rules as a means of destroying mosquito larvae, experience with other reservoirs having demonstrated its feasibility.

Snail populations grow quickly in shallow, quiet water, with aquatic vegetation, conditions usually found at the edge of reservoirs and in irrigation canals. The disease is transmitted when the larvae penetrate the skin and it usually happens when people enter the water in these places. One of the most important measures to be taken, as referred by Obeng (1978) is to provide a safe water supply for the rural populations in the areas where these projects are being developed, avoiding the contact with contaminated water. Also the fluctuations of water level in the reservoir help to control snail populations.

4.3.3 Sedimentation and erosion

Large reservoirs like Pequenos Libombos usually have a high "trap efficiency" for the sediments transported by the river. This is accounted for in the reservoir design by including a dead storage component in the total capacity, according to the expected useful life of the reservoir. Erosion can be expected downstream of the dam, the river picking up material from the bed and banks to maintain its equilibrium. The amount of sediment the river will need to maintain the equilibrium depends also on the new flow regime introduced by the reservoir. No study has yet been made for the Pequenos Libombos reservoir to assess these effects. The dam has an especially designed spillway, located in the main valley, which is expected to pass downstream a large part of the sediments carried during a flood, mainly the finer particles.

4.3.4 Resettlement of population

Resettlement of the population living in the area that is going to be flooded by the reservoir is usually a difficult problem but it could be handled in the case of Pequenos Libombos reservoir where the total population that had to be displaced was less than five thousand. They are now relocated in a new village.

5. New Studies

Besides the design of the new irrigation schemes, other studies are being conducted or will start in the near future.

Two of these studies concern the operation of the Pequenos Libombos reservoir. The first one is an allocation model to define operating rules for monthly and 10-day periods. These operating rules have to consider the water supply to Maputo, to which absolute priority is given, the different irrigation schemes, hydropower production and flood control. Hydropower will be a by-product of water discharged for other uses. Flood control will appear in this model essentially as an analysis of the impact of reserving flood storage on the reliability for other users. Additional water releases to control saline water intrusion can be included in the model as well as the regular fluctuation of water levels in the reservoir and special discharges from the hypolimnion.

The second model is to be used for operation during floods. This model will include various components like a telemetric network, special data processing, a rainfall-runoff model and routing procedures. This model will be an important component in a flood warning system to be installed in the basin and which include a model to study the propagation of the flood wave discharged by the reservoir.

Two important studies, not yet started, concern the problems of erosion and sedimentation downstream of the dam and an environmental impact assessment. The erosion problems that can occur due to the retention of sediments in the reservoir need to be assessed so that counter-measures can be taken in time where needed. In relation to environmental problems, there is a lot of dispersed information but it has not a unified perspective and it lacks the depth of analysis that was applied to the engineering and economic studies.

6. Summary and Conclusions

A brief presentation has been made of the past and future water development in the Umbeluzi basin concerning both Mozambique and Swaziland. Urban water supply and irrigation have been assumed to be the main water uses and a short description of the agreement between the two countries, the effects of the drought and the "Domoina" flood has been made. The need to regulate streamflow was put in evidence as the basis for the construction of M'njoli dam in Swaziland and Pequenos Libombos dam in Mozambique. The positive impacts of water development in Swaziland and Mozambique, resulting in a reliable urban water supply, irrigation, flood control and other purposes were described and also the adverse impacts that can occur related to water quality, health, sedimentation and erosion.

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Figure 16.1: The Umbeluzi River Basin

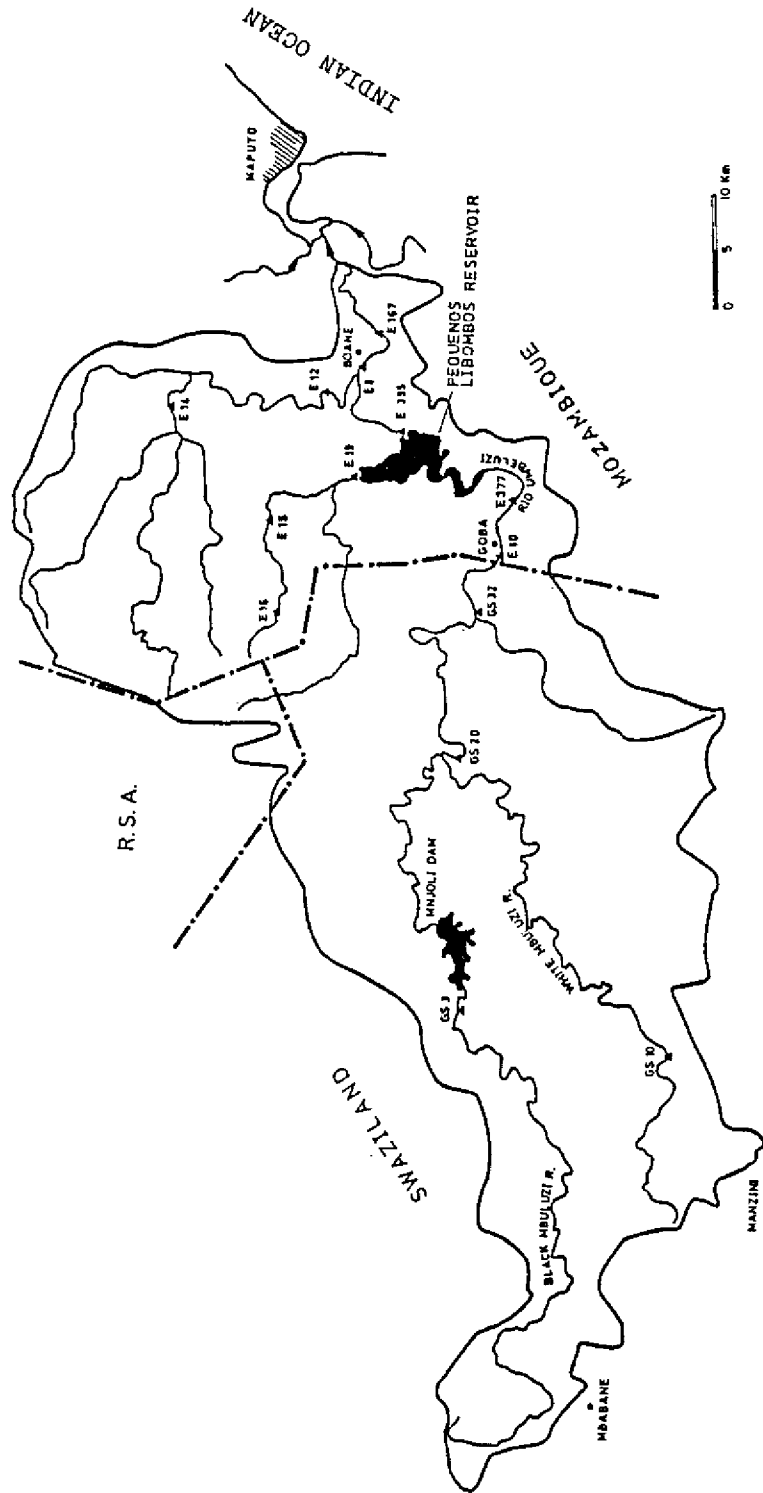


Figure 16.2: 1981/83 Drought at GOBA station

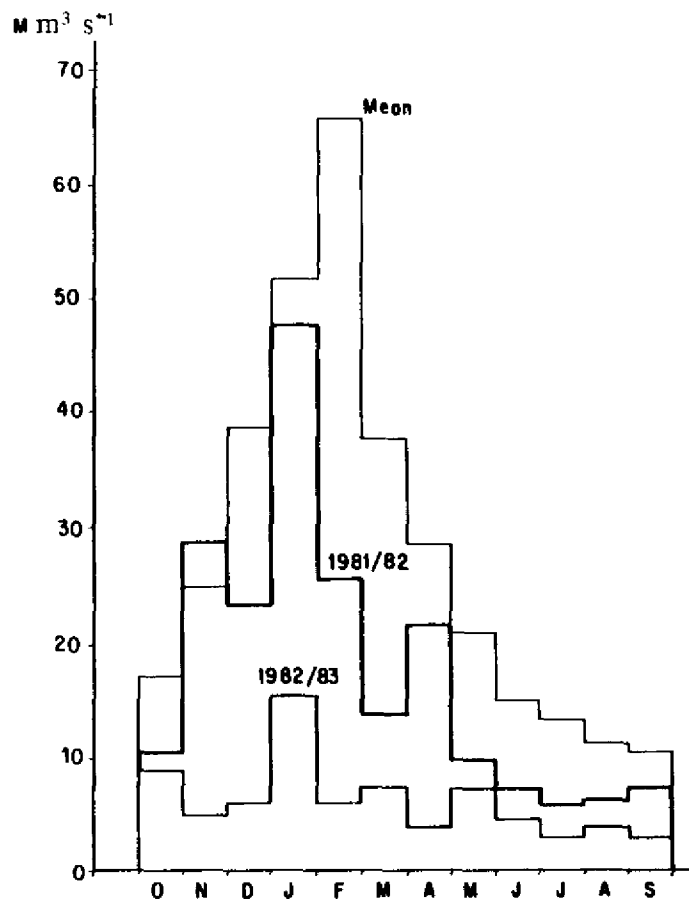
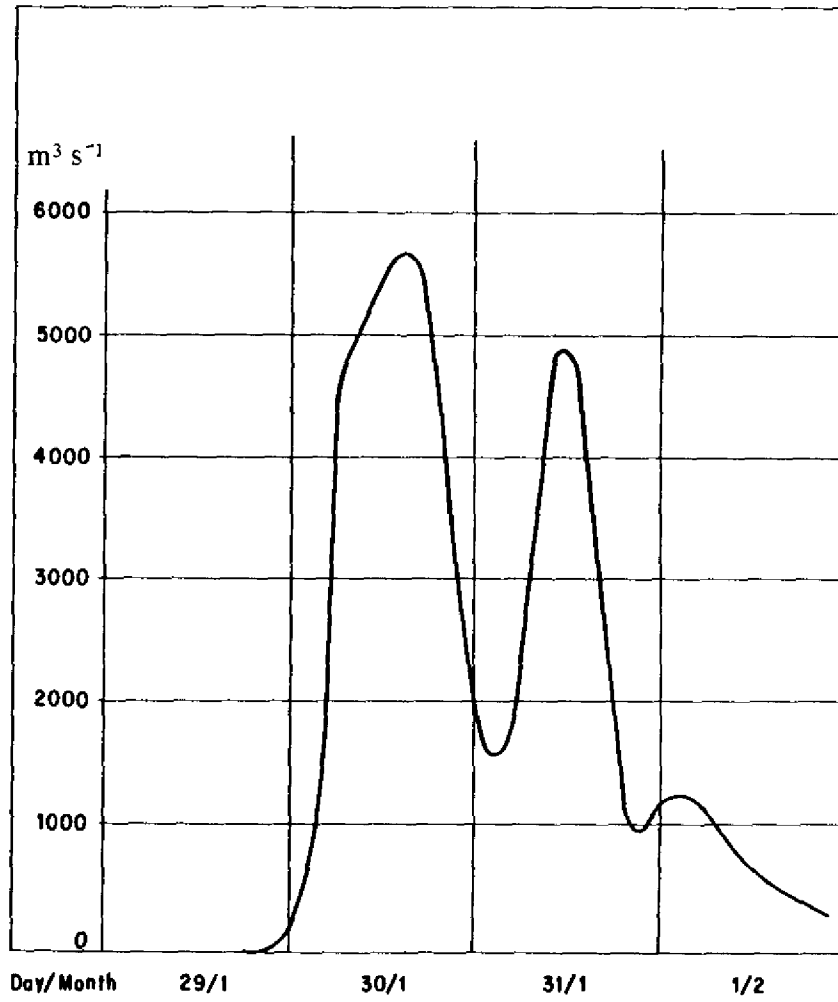


Figure 16.3: "DOMOINA" flood hydrograph at P. Libombos



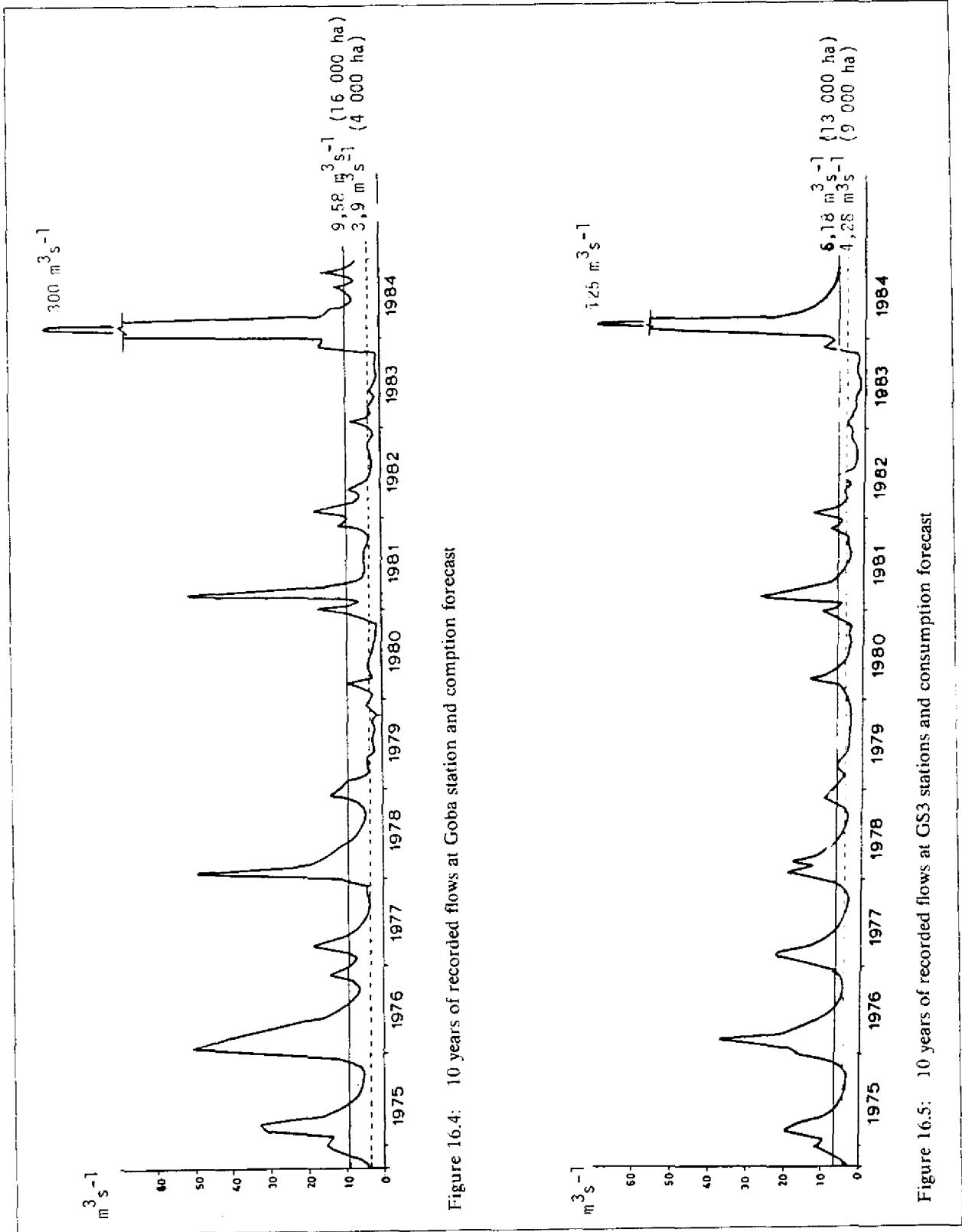


Figure 16.4: 10 years of recorded flows at Goba station and compition forecast

Figure 16.5: 10 years of recorded flows at GS3 stations and consumption forecast

PAPER 17

TEN YEARS AFTER COMPLETION OF CABORA BASSA DAM

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1. Introduction

The Zambezi rises on the South Equatorial Divide near the conjunction of the boundaries of Zambia, Angola and Zaire and flows for a distance of approximately 2 700 km to the Indian Ocean, which it enters about 240 km north of Beira in Mozambique. Its catchment area is about 1 300 000 km² (Figure 1).

The Zambezi River Basin lies within the extensive southern African plateau and the southern sector of the African Rift system. The major part of the river basin lies within the tropical belt south of the equator. It is characterized by a reliable pattern of rainfall, which is estimated at 900 mm per annum.

The Upper Zambezi rises at about 1 500 m above sea level. In the first section of its course the river drops about 330 m in altitude and is fed by more than a dozen tributaries of varying sizes. After a series of rapids and falls the river reaches the Victoria Falls at an altitude of about 900 m. Before however reaching the Victoria Falls, the Zambezi River is joined by the Chobe River together draining about 285 000 km². The average annual discharge amounts to about 50 Gm³.

The river's middle course extends about 1 000 km from Victoria Falls to the eastern end of Cabora Bassa in Mozambique.

The most notable feature of the Middle Zambezi is the Kariba man-made lake. Kariba Dam is situated at Kariba Gorge and consists of a double curvature concrete arch dam with a maximum height of about 130 m and a crest length of about 600m. Six floodgates permit a discharge of 9 400 m³ s⁻¹. Zambia and Zimbabwe receive most of the electricity produced at Kariba Dam. The dam was completed in 1959 and thus the environmental impacts already have a history of almost 30 years.

Lake Kariba covers an area of about 5 400 km² at 486.5 m above sea level and has a volume of 160.4 Gm³. The lake length is about 280 km from the dam to Devil's Gorge and is 30 km across at its widest point. The reservoir gains 4.4 Gm³ per annum by direct precipitation (820 mm) and loses 8.4 Gm³ by evaporation (1 560 mm). Thus the total

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amount of water available at the Kariba Dam amounts to about 46 Gm³ annually, of which 9 Gm³ are received from the tributaries downstream of the Victoria Falls.

Several other impoundments were established within the Zambezi River Catchment in Zimbabwe amongst which are Mcllwaine (reservoir capacity 38.8 Mm³) and Ngesi (reservoir capacity 26 Mm³).

For hydro-electric power generation a dam was built in 1972 on the Kafue River at Kafue Gorge and a second dam was built upstream, near Itesitesi.

In view of all these projects the Zambezi River, when entering the territory of Mozambique can be considered to be a regulated river that has lost its natural pattern of flow variations.

2. The Cabora Bassa Dam

Where the Luangue River enters the Zambezi River on its left bank begins the territory of the People's Republic of Mozambique. This is also the extremity of the largest man-made lakes, the Cabora Bassa.

The initiative for the development of the Zambezi River by means of the Cabora Bassa was taken by of the Portuguese Government in 1957 when it launched the first of several investigations to determine the feasibility of settlement and general economic development in the Upper Zambezi Valley in Angola and the Lower Zambezi Valley in Mozambique.

As early as 1959 the advantages of a major hydro-electric project at Cabora Bassa had been assessed. From the outset the rationale for such a project was twofold - to sell electricity to the Republic of South Africa, the major potential customer in the region, and to promote economic development in Mozambique. By the mid-1960s South Africa had confirmed its interest in the project and Portuguese engineers had selected a site for the dam and completed some exploratory drilling and excavations.

Construction of the dam started immediately after the creation of an international consortium in September 1969. The lake behind the dam wall started to form on 5 December 1974. During the first half of 1975 the lake was filled. The project was finally completed in 1977, and the last installed generator brought the power capacity up to 2 075 MW in January 1979. There is a possibility to install a generator on the North bank and raise the total to about 4 000 MW. The lake has a reference level of 326 m.a.s.l. and a surface area of 2 665 km². The extreme length and width are respectively 246 and 39.8 km with a shoreline of 1 775 km. The Cabora Bassa reservoir is situated between latitudes 15°28'S and 16°00'S and longitudes 30°25'E and 32°44'E. The western extremity of the reservoir reaches the junction of the Mozambique, Zambia and Zimbabwe frontiers. The dam height was designed so that the reservoir would not enter neighbouring states.

For management purposes the reservoir has been subdivided into seven basins, based on shoreline morphology and administrative considerations. These sub-basins bear the following names: Zumbo, Messenguezi, Carinde, Mucanha, Mague, Chicoo and Garganta.

3. The Lower Zambezi River

The lower Zambezi, including Lake Cabora Bassa, lies within Mozambique (Figure 2). The river crosses the border into Mozambique near the township of Zumbo, at an elevation of 330 m and flows into the Cabora Bassa reservoir. At the dam site the gorge is very steep-sided with a depth of about 600 m. From the dam, the river continues in this gorge for a further 30 km before entering the peneplains. The course of the river is only slightly meandering to Lupata, flowing in a well-defined channel between 800 and 1 000 m wide. After passing through a gorge at Lupata at 95 m above sea level, the river enters its major flood plain. The final 350 km from Lupata to the Indian Ocean are characterized by a course between 3 and 5 km wide, heavily braided with ill-defined banks. In the dry season, the Zambezi may flow in several channels that, during the wet season, merge together into a single, swift-flowing body of water.

At its mouth (Figure 3), the Zambezi splits into a wide, flat and marshy delta, obstructed by sandbars. The delta can be considered to start at Mopeia, 150 km from the Ocean, and tidal influence is evident over the last 80 km. There are two main channels, each again divided into two. The wide channel splits into the Catarina River to the north and the main mouth of the Zambezi to the south (Boca do Zambezi). The western channel forms both the Muselo River and the smaller Melamlse River. North of the main delta the Chinde River separates from the Zambezi's main stream to form a navigable channel leading to a shallow harbour. At its mouth, the average annual discharge amounts to about 106 Gm³.

There are four major tributaries entering the Zambezi within Mozambique. These with their catchment areas are:

Luia	27 634 km ²
Revuboe	15 540 km ²
Luenha	54 144 km ²
Shire	158 274 km ²

The Luia, Revuboe and Luenha all rise on the escarpment of the central African plateau. The climate there is strongly seasonal and the dry season long. Runoff is rapid and these tributaries have little flow in the dry season. The Shire is a major river in its own right which drains Lake Malawi. As such its catchment comprises the whole of Malawi and extends into Tanzania. Substantial self-regulation of the river is afforded by its passage through Lake Malawi and swamp areas in the lower reaches.

As it enters Mozambique, the Zambezi is a large river with an average annual runoff of 80 Gm³ at Cabora Bassa, which is an average discharge of 2 440 m³ s⁻¹. In the period of observations between 1960-1984 at Tete the mean flow was 2 540 m³ s⁻¹ with a minimum and maximum flow of respectively 190 and 17 145 m³ s⁻¹. Runoff generated in Mozambique is estimated as 18 Gm³.

The high flow months are January to April with the peak usually occurring in February or March. The flood contributions of the tributaries Luia, Revuboe and Luenha to the Zambezi, are relatively high in terms of flood peak, despite being small in volume. For example, these three tributaries combined have a five-year return period flood of about 4 000 m³ s⁻¹. This is to be compared with a threshold release from Cabora Bassa in the region of 7 000 m³ s⁻¹.

The 1981 flood in the Lower Zambezi, indicates that the contribution from the tributaries downstream of the Cabora Bassa Dam can be occasionally as high as $5\,650\text{ m}^3\text{ s}^{-1}$

The Luia and Revuboe tend to produce their highest floods in February and March. The Luenha, having its catchment further south, is affected first by the movement of the intertropical convergence zone and its floods generally occur in January or February.

The effects of upstream impoundment upon the riparian habitats of African flood plain rivers has been demonstrated in many studies including the Zambezi River. Impoundment of the Zambezi started in 1959 with the creation of the Kariba Lake. Later in 1975 the Cabora Bassa reservoir was completed.

Davies et al. (1975) stated that the creation of Lake Kariba - and consequent flow regulation - has allowed salt water intrusion in coastal areas, reduced silt loads and has destroyed large areas of mangrove along the coastal floodplain.

Tinley (1975), on the other hand, claimed that reduced flooding in the delta area has dried out the rich alluvial soils - many of which have become alkaline or saline - and savanna vegetation has invaded the area.

The additional regulation of the Zambezi River due to the construction of the Cabora Bassa Dam should have aggravated the adverse effects or in general the impact on the ecology of the floodplains in Mozambique. Unfortunately, there is little evidence due to almost complete lack of investigation during the 10 years after the construction of the Cabora Bassa Dam. There are relatively large amounts of hydrological data that could be helpful with the analysis of the possible effects of the Zambezi River impoundment.

Some effects of river impoundment on the downstream environment are obvious, others are dubious. One can expect, obviously, a smaller part of the area to be flooded and then on an irregular basis.

Regulation of flow through impoundment also means an increase of low flows. As a result a decrease in salt water intrusion in coastal areas has to be expected. In the case of the Zambezi River the construction of the Kariba Dam increased the low flow from about $300\text{ to }600\text{ m}^3\text{ s}^{-1}$ (average $450\text{ m}^3\text{ s}^{-1}$) to about $600\text{ to }900\text{ m}^3\text{ s}^{-1}$ (average $750\text{ m}^3\text{ s}^{-1}$).

The daily records at Matundo (Tete-Mozambique, 135 km downstream of Cabora Bassa Dam), shown in Figure 4, for the years 1962/63 and 1968/69 chosen as example, demonstrate very low flows in October and November, as low as $500\text{ m}^3\text{ s}^{-1}$ in the last analyzed hydrological year.

Although an augmentation of low flow in the Lower Zambezi due to the impoundment in the Kariba Dam was measured, the river was far from being regulated (Figure 5). As shown on Fig. 4, 5 years and 10 years after construction of Kariba Dam, a wet period could be clearly distinguished with flows exceeding $11\,000\text{ m}^3\text{ s}^{-1}$. Evidently the occurrences during the year and extending over the period were strongly modified.

The construction of the Cabora Bassa Dam imposed a much stronger effect on the flow of the Lower Zambezi. As measured at Matundo-Tete the monthly runoff variation has a much lower amplitude after completion of the dam. As shown on Fig. 5, the difference between the lowest runoff in October and the highest runoff in March was about 10.5 Gm^3 ,

before the construction of the dam. After the closure of the dam the variation was much lower, of the order of 4.1 Gm^3 . The exceptionally big flood of 1977/78 was excluded, since in the period analyzed before the construction of the Cabora Bassa Dam there was no annual runoff of that magnitude. Most characteristic is, however, the existence of several peaks after the closure of Cabora Bassa with a completely unexpected pattern.

After the construction of the Cabora Bassa Dam the Lower Zambezi became a river without any characteristic flow pattern as show for example on Figure 7 for the hydrological year 1978/79. What is also important is that it is very difficult to find a similar flow pattern during any year after construction of Cabora Bassa Dam. How different the hydrological years can be as far as flow is concerned in the Lower Zambezi (Matundo-Tete) can clearly be seen from the example shown on Fig. 8. The uncharacteristic flow variation has a marked effect on the habitat of wildlife and an adverse effect on land cultivation in the floodplain area - including the floodplains of the Shire.

Evidently there was a flow augmentation with, even during the extremely dry year 1983/84, a minimum flow of about $1\,000 \text{ m}^3 \text{ s}^{-1}$ which was maintained during the whole period. The monthly average was raised from 2.6 Gm^3 to 4.8 Gm^3 .

Records of river heights at the downriver sites of Dona Ana and Marromeu show a long history of flooding. The maximum level of the 1926 flood was used to define the heights of protective dykes around the Sena Sugar Estates at Marromeu and Luabo. This level was subsequently exceeded in 1939, 1940, 1952, 1958 and 1978.

According to Rendel, Palmer and Tritton (1979), floods of up to $9\,000 \text{ m}^3 \text{ s}^{-1}$ (in Lupata) can be expected most years below Cabora Bassa.

Before the construction of the Kariba Dam, in the period 1932-1958 (no records for the years 1953 and 1954), there have been a total of 266 days with a flow above $9\,000 \text{ m}^3 \text{ s}^{-1}$ or on average about 10.6 days each year. The floods above that threshold have not occurred every year but in 64 percent of the years analyzed.

After the construction of Cabora Bassa Dam, flows above $9\,000 \text{ m}^3 \text{ s}^{-1}$ have not been registered except for the years 1977/78 with the unusual flood and mismanagement of the dam. Within the period 1978-1985 there have been only three years when the flow was above $7\,000 \text{ m}^3 \text{ s}^{-1}$ as measured at Tete-Matundo, during a total of 31 days. During the other 4 years of records, the flow was always below $7\,000 \text{ m}^3 \text{ s}^{-1}$. Flows above $5\,000 \text{ m}^3 \text{ s}^{-1}$ can be expected almost every year with a duration of 10 to 60 days.

The flooded area for a flow of $5\,000$ to $7\,000 \text{ m}^3 \text{ s}^{-1}$ between Lupata and Marromeu was estimated by Rendel, Palmer and Tritton (1979) as shown in Figures 9 and 10. Although the aforementioned authors have used flow data at Lupata, the data from the hydrometric station at Tete-Matundo do not differ very much. Evidently as discussed before, there could be a considerable increase of flow downstream of Tete due to the contributions of the tributaries which however do not necessarily coincide with periods of high release from Cabora Bassa.

The above data are note claimed to be precise but serve to demonstrate the reduction in magnitude, timing and extension of floods.

The Delta area is relatively flat and even small changes in water level can cause extensive flooding. The reduced variation in flow and the substantial decrease of the

peakflows has a distinct negative effect on the grassland and grassland swamps vegetation and as a consequence on the wild animals.

At Marromeu the rise from the normal flow of $1\,500\text{ m}^3\text{ s}^{-1}$ to $5\,000\text{ m}^3\text{ s}^{-1}$ means an increase of water level of about 3 m (Figure 12). The effects of such arise are not immediately transferred in flood to the Marromeu cross-section. Only at about $12\,000\text{ m}^3\text{ s}^{-1}$ does the flooded area of the Cua-Cua River (which starts to overtop at flows as low as $3\,000\text{ m}^3\text{ s}^{-1}$) join with the left bank plains in the Marromeu region.

4. Erosion, Sediments, Lake Siltation, River Bed Erosion

In the tropical zone where the Zambezi River Basin lies, the rainfall is very heavy, occurring usually within a period of four months. In general the soils in the Zambezi River Basin are vulnerable to erosion. The actual process of erosion by water is activated by the force of the rain and also by runoff arising from it. The sediments transported by small rills or channels or gullies may enter the natural or the man-made lakes, where it will settle due to a reduction in the velocity of the flow.

There is only limited information available on soil erosion and sediment yield in the Zambezi River Basin.

Although there are some data on the mean sediment load in the basin regulated by Kariba Dam, the mean yield estimated by Bolton (1984) is very uncertain and lies in a wide range of $40\text{-}400\text{ t.km}^{-2}\text{ year}^{-1}$.

The area drained by the Zambezi River between Kariba and Cabora Bassa Dams is about $225\,000\text{ km}^2$. The main part, i.e. about 66 percent of that area, is drained by the Luangua River Basin in Zambia. Bolton (1983) suggested that the Luangua Basin, which covers $148\,000\text{ km}^2$, provides by far the most important source of sediment entering the Cabora Bassa Reservoir. The suggestion is supported by some measurements as well as by the erosion hazard map of Africa (D'Hoore, 1964). Based on a mean annual discharge of approximately 17 Gm^3 , rates of sediment deposition in Cabora Bassa in the range of $15\text{ to }150\text{ Mt year}^{-1}$ were given. Together with other tributaries and the Zambezi River Basin proper, the total amount of retained solids according to Bolton (1984) could vary in the range of $0\text{ to }200\text{ Mt year}^{-1}$. For comparison the sediments captured by the Aswan Dam on the Nile River amount to 100 Mt year^{-1} , causing serious problems along the river banks and on the beaches of Alexandria. The upper value seems however to be unrealistic, taking into consideration the predominating vegetation in the Luangua River Basin (Wite, 1983) and the assumed higher "average" value of the suspended sediment concentration equal to $9\,000\text{ mg l}^{-1}$. It is hard to accept such a value, for which the fluid can no longer be classified as water but rather as mud or sludge. Results of measurements by different authors given by Bolton (1983) are in the range of $200\text{ to }400\text{ mg l}^{-1}$, a much lower "average" concentration.

An assumed value of $3\,000\text{ mg l}^{-1}$ will most probably not be an underestimate. As a result the upper range of possible sediment carried by the Luangua to the Cabora Bassa Reservoir is estimated as of about 50 Mt year^{-1} .

Analyzing the other part of the Zambezi River Basin in between Kariba and Cabora Bassa the total estimated sediment load can be reduced to about $70\text{ to }75\text{ Mt year}^{-1}$, with the lower limit in the order to 20 Mt . Thus the "dead" storage part of the Cabora Bassa Reservoir would have a life in the range of $180\text{ to }600\text{ years}$. After 10 years of operation of the Cabora Bassa Reservoir, no sediment deposition measurements have been made and therefore not even an approximate evaluation of the above estimates is possible.

The only evident result of retention of sediments in the Reservoir is the "clear" water at the dam.

In the alluvial stretch of a river one can expect degradation of the river channel downstream of a dam when no sediments received from upstream.

The considerable erosive power of the Zambezi River downstream of Cabora Bassa, especially downstream of Tete, can be seen in the constant changes in the position of "sand islands" and river banks.

It was concluded by several authors that accurate prediction of the amount of accretion or degradation in an alluvial stream downstream of a dam is not possible. No attempt was made to use the existing theoretical models primarily due to a time scale far too long in comparison with the elapsed period of 10 years and due to lack of equipment to perform special measurements for model verification.

Downstream of Cabora Bassa, the river is continuously supplied with sediment by the Revoube and Mavuzi Rivers (upstream of Tete). The rivers carry sediment from the district of Angonia reported by the Mozambican authorities to be affected by serious soil erosion. In a part of this district serious gully and sheet erosion occur, due to overstocking of cattle. No measures seem to be taken to correct this situation.

Very little information is available on suspended solids and river bed characteristics. Between 1963 and 1971 data have been collected for the purpose of planning channel modifications in connection with the expected development of navigation.

The French consultant Sogreah (1981) summarized the results of measurements and has shown the following distribution of samples of riverbed sand taken in Tete:

d10 = 0.297 mm
d25 = 0.420 mm
d55 = 0.555 mm
d85 = 1.0 mm
d95 = 2.5 mm

and at Marromei:

d30 = 0.240 mm
d90 = 0.500 mm

Bolton (1983) shows median grain size at Tete in the range of 0.48 to 0.74 mm. The same author gives only one median grain size for Marromei, equal to 0.27 mm.

The above data show good consistence and thus can be used for further evaluation of the phenomena related to riverbed erosion.

Savenije (1980) calculated that 50 percent of the bed erosion found near dam will be observed at the Tete cross-section only after 86 years.

Assuming the calculation as correct, no visible changes should have occurred at Tete 10 years after the closure of Cabora Bassa. As a matter of fact it is very difficult to verify a general tendency since the river bed is and was always very unstable. The relatively small

diameter of the sand grains can be considered as responsible for easy movement of the sand from one place to another, whenever the water velocity is high enough.

The critical water velocity for bed erosion of sand $d_{50} = 50$ mm is in the order of 0.2 to 0.3 m s^{-1} . This is a very low velocity in comparison to the prevailing velocity of the Zambezi River (at Tete) after the construction of the Cabora Bassa Dam. With a flow maintained in general above 1 000 $\text{m}^3 \text{s}^{-1}$ the average water velocity is always above 0.8 m s^{-1} which can be seen on Fig. 13. There are unfortunately not enough data to evaluate the solid transport before and after the construction of Cabora Bassa Dam. It is evident, however, that before the completion of the aforementioned dam, there had been long periods during the year with water flows below 1 000 $\text{m}^3 \text{s}^{-1}$ (about 450 $\text{m}^3 \text{s}^{-1}$), and consequently with much lower water velocities and thus with periods of less river bed erosion.

Whenever an increase of flow occurs above normal, larger quantities of sand are transported downstream and an immediate lowering of the river bed can be observed. As an example the effects of the Dec. 1979-Jan. 1980 flood period are shown on Fig. 14.

Increase of flow over short periods result in distinct changes of the cross-section. If in one part of the river cross-section (Figure 15), due to a high flood wave, a lowering of the bed is observed, in the other part, heavy deposits occur.

The changes in the profile of the river occur over short periods showing constant accretion and scour. As shown in Figure 16 after a steady flow in September and the first part of October a substantial deposit was noticed, which was washed away during the next two weeks of higher flow. The deposition of sand in a particular sector of the river cannot be related directly to the magnitude of flow. As is evident in Figure 16, the deposition of sand occurred in a period with a flow of about 2 000 $\text{m}^3 \text{s}^{-1}$ while an increase to 6 000 $\text{m}^3 \text{s}^{-1}$ caused a washout of the deposits. In a previous period between March and August 1978 with an even higher flow in the range of 7 500 $\text{m}^3 \text{s}^{-1}$ accretion or rather displacement of sand was observed (Figure 17).

With rather exceptional low flow in the period August 1978-April 1979 the cross-section of the River Zambezi in Tete was reduced by more than 50 percent from 2 800 to 1 300 m^2 . Later, higher flows have restored the profile of the cross-section, washing away at least in part a layer about 4 m thick.

As explained before there is a continuous accretion and scour of the river bed with continuous displacement of sand bars, which on the long term does not show any stabilization nor definite tendency. The measurements made in August 1985 and in April 1986 demonstrate the impossibility of showing erosive effects or of making any forecasts (Figure 18).

In the period 1983-1984 one of the piers of the bridge (along which the profile measurements are made) at a distance of 270 m from the right bank, has been under reconstruction and therefore an artificial obstacle existed in this region responsible for the exceptionally high build-up of sand. The high water in February and March 1986, however, almost restored the profile of the cross-section to that of before May 1983.

There are no data on erosion in the Lower Zambezi (below Tete), which most probably will be of the same order of magnitude. In the Lower Zambezi the contributions of sediments from the tributaries and especially from the Luenha River are probably responsible for extension if any of the effects of Cabora Bassa on the Zambezi River bed.

With no firm data on the progress of bed or bank erosion in the Lower Zambezi a statement can however be made with confidence about the navigability of the river. In documents prepared before the construction of the Cabora Bassa Dam it was believed that the trapping of sediments in the reservoir would significantly contribute to self-regulation of the river and increase the potential for navigation.

Ten years after completion of the dam it can be clearly seen that in the time-scale of economic planning, no self-regulation can be expected and to render the river navigable would require an enormous economic effort.

Due to the retention of sediment in the Cabora Bassa Reservoir, the net amount of sediment deposited in the Lower Zambezi, and especially in the floodplains, has obviously decreased. No quantitative estimate is however possible. Taking into account on the other hand the length of the Zambezi River below the Dam of about 500 km, it seems to be unlikely that it will be possible to observe distinct effects on the floodplains or on the delta.

Much more marked are the results of flow regulations and less land was inundated on a more or less regular basis. With a low agricultural intensity in Mozambique, the river regulation in the Lower Zambezi has rather negative effects on the ecology in general and on the wildlife in particular.

5. Water Quality

During the first years after impoundment of Cabora Bassa the water quality in the reservoir and downstream was primarily controlled by the new ecological conditions. The remaining trees when totally submerged have created good shelter conditions for aquatic life and contributed notably to the increase of organic substances in the Zambezi River water. Close to the shores the remains of trees and bushes held up large masses of floating plants that otherwise would have drifted down the lake. Although there was a retention and proliferation of floating aquatic plants they never became a hazard in the operation of Cabora Bassa Dam. The plant cover was and is relatively small (some few square kilometres) and the prevailing southerly winds keep it away from the gorge.

Aquatic vegetation in a lake like Cabora Bassa, if confined mainly to inshore regions, is an advantage for fish life; there is a source of food in the plants themselves, in the algae and invertebrates that encrust their surfaces and in the small invertebrates that live amongst them. They also provide an essential refuge from predators for young fish.

The water quality is favourable for aquatic life, showing high levels of dissolved oxygen, being slightly alkaline and having enough electrolytes.

In most parts of the Cabora Bassa Reservoir the concentration of O₂ is usually between 6 and 7 mg l⁻¹. Measurements made close to the dam have shown little stratification. Also no serious temperature stratification was found. Water temperature averaged about 23° C with a minimum in July of about 18 to 21°C and a maximum in February of 30°C.

The long term effects of Cabora Bassa Dam on the downstream water quality can include possible changes caused by trapping of sediments in the reservoir, and those caused by chemical changes affecting water in the reservoir. One possible effect on water quality could be due to very high evaporation from the surface of the reservoir. This phenomenon could be responsible for an increase in water mineralization.

The mean monthly net reservoir evaporation as the reservoir evaporation minus the increase in runoff over the reservoir area was calculated by SWECO/SWED POWER (1982). Evaporation has a bimodal distribution peaking in April and again, more strongly, in October.

The mean annual evaporation from the Cabora Bassa Reservoir has been estimated to be 1500 mm. The mean annual rainfall over the reservoir area attains 650 mm, based on over 40 years of data and up to nine rainfall stations covering the vicinity of the reservoir area. Year to year variations are between 20 percent and 40 percent both in quantity and duration (Friedel, 1978). Virtually all rain falls between November and March.

Based only on the mean annual data, a loss of water of about 4 Gm³ can be calculated. It is interesting to note that due to the much larger surface of the Kariba Lake (about 5 400 km²) losses of about 8 Gm³ can be expected from that reservoir. In total a loss of about 17 percent of the annual runoff can be anticipated.

As a result of water losses due to evaporation, increase of water mineralization was observed during the last 14 years, i.e. from 1972 when first measurements of salinity (electric conductivity) started. The Zambezi River waters belong to a group of large Mozambican rivers with relatively low salinity (Suschka, 1986) (Figure 19).

Comparing conductivity (Figure 20) or alkalinity (Figure 21) measurements of the two periods 1972-1973 and 1982-1985, an increase of salinity becomes evident.

Also, measurements of chlorides at the gorge of the Cabora Bassa reservoir in the period 1977-1986 have shown an increase from about 4 mg l⁻¹ in the period 1977 to 1980 to about 12 mg l⁻¹ during the period 1981 to 1983. Heavy rainfall in January-March 1984 caused a temporary decrease of chlorides concentration to about 7 mg l⁻¹. After six months i.e. after partial mixing of the water in the reservoir, an increase to about 12 mg l⁻¹ was observed. This phenomenon was repeated in January-February 1985 and October-December 1985. The lesson learned is, that in the wet period and in particular during an especially wet year, renovation is possible.

It is assumed therefore that a slower increase in mineralization will take place over the next period of time. On the other hand, increase of agricultural activities upstream of the Cabora Bassa Reservoir as well as in the basin of the Reservoir could contribute significantly to the increase of water mineralization.

The main potential for agricultural production is however in the Lower Zambezi River basin. Flood regulation of the Zambezi River was expected to allow development of gross area of 2.5 Mha of prime agricultural land. In the foreseeable future 210 000 ha are expected to be irrigated, this requiring about 250 m³ s⁻¹ of water, or about 10 percent of mean annual flow.

Industrial pollution so far has not been a serious problem. The main pollution sources at the moment exist in Zambia in the Kafue River Basin. At full production capacity, industry will be a serious source of pollution of the downstream reaches of the Kafue River and the Middle Zambezi.

In Mozambique there are many ambitious plans for industrial development in the Zambezi Basin. There is reasonably cheap energy available and some basic minerals in quantities sufficient for large-scale export. One of the main water consumers and polluters

will be the coal mining industry, with an expected increase of production to about 6 Mt per year, since a large part of the extracted coal will be washed in the process of preparation-enrichment. Also metallurgical industries are planned in Tete. The highest water consumer will however be the future aluminium smelter.

The total industrial water consumption in the region of Tete is expected to be in the range of 6 to 9 m³ s⁻¹ which is very little in comparison with the expected agricultural consumption. Nevertheless, some of the industrial plants can have a serious impact on the water quality over long reaches of the Zambezi River.

Close to the Zambezi River delta localized sugar refineries constitute a serious threat to the unique ecological system of that region.

6. Conclusions

The specific impact of water resources development through impoundment is strictly related to the socio-economic and ecological environment conditions prevailing in the period during which the impact is assessed. It would be wrong to accept a static approach or to make long-term recommendations based on more or less sophisticated analyses. The problem of environmental impact assessment of large water projects has been discussed and described in many publications. Although it was concluded on several occasions that a different approach should be adopted for developed and developing countries, it is our feeling from the experience in the Zambezi River Basin that such a philosophy is an over-simplification and does not necessarily apply universally.

For example the DES/UNEP International Seminar (1984) stated that for Africa, in the case of river impoundments, impacts on soil and changes in soil conditions, seismology, salt water intrusion and mangroves and wetlands are of little importance.

In fact in the Zambezi River Basin the construction of Kariba Reservoir induced a major earthquake of intensity 5.8.

Also salt water intrusion and the destruction of mangroves and wetlands in the delta area is of prime importance. In this paper however attention was given to those aspects that could be evaluated on the basis of measurements, avoiding speculations and assumptions.

Although sediments are being trapped in the Cabora Bassa, no evident changes in the river bed configuration through aggradation or degradation have been measured. A much longer period will be necessary to find noticeable effects. Storage of water in Cabora Bassa has changed considerably the hydrological cycle of high and low flows. The annual flood peak has been attenuated and on an average of 10 years a bimodal flow pattern was found. Analyzing each year separately, however, the occurrence and duration of peak flows is completely irregular and can happen at practically any time. Destruction of ecological systems has been reported such as the washing away of reptiles' eggs.

Water quality changes have become evident mainly expressed by an increase of the electrolytes concentration in the water. The basic reason for this is most probably the high evaporation from the lake surface. An increase in the electric conductivity from about 100 to 150 was found to have occurred over a period of ten years. Data on chlorides concentration in the Cabora Bassa Lake permitted to conclude that water renovation occurs due to heavy rains in some of the wet periods. It is expected that because of this, the increase of water mineralization will continue at a lower rate. On the other hand, the expected development of irrigated agriculture can affect drastically the anticipated changes.

In general, the changes observed so far in the environment of the Zambezi River basin due to the river impoundment have been found to be of a limited nature. Some changes (impacts) are still to be discovered and evaluated. There are however most probably much more serious impacts to be experienced in the future if the industrial development plans are executed without the introduction of proper environmental protection measures.

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Figure 17.3: Delta of Zambezi River

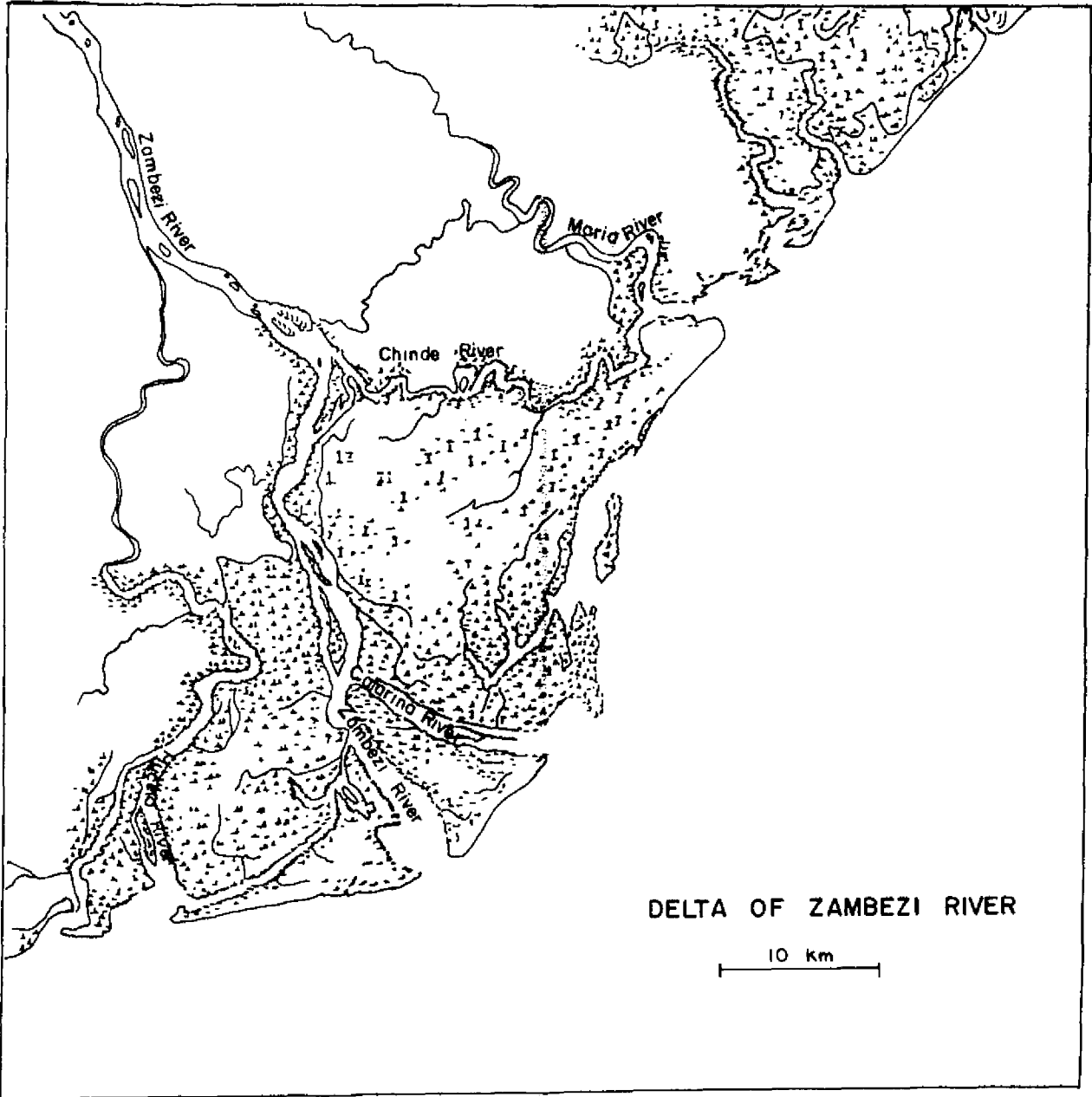


Figure 17.4: Daily flows at Tete-Matundo (E387), year 1962/63

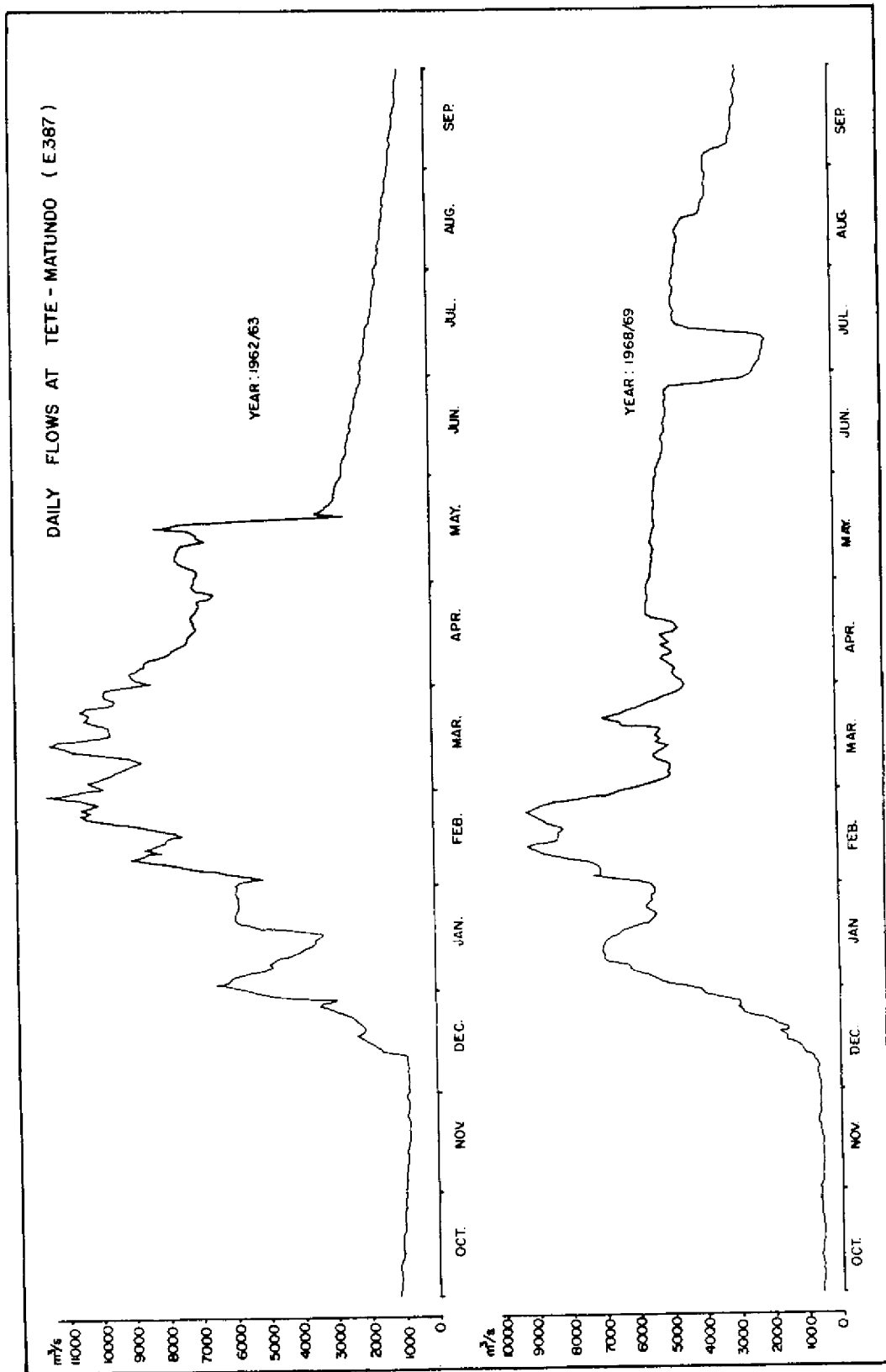


Figure 17.5: Daily flows at Cabora Bassa in the period 1964/65 - 1965/66

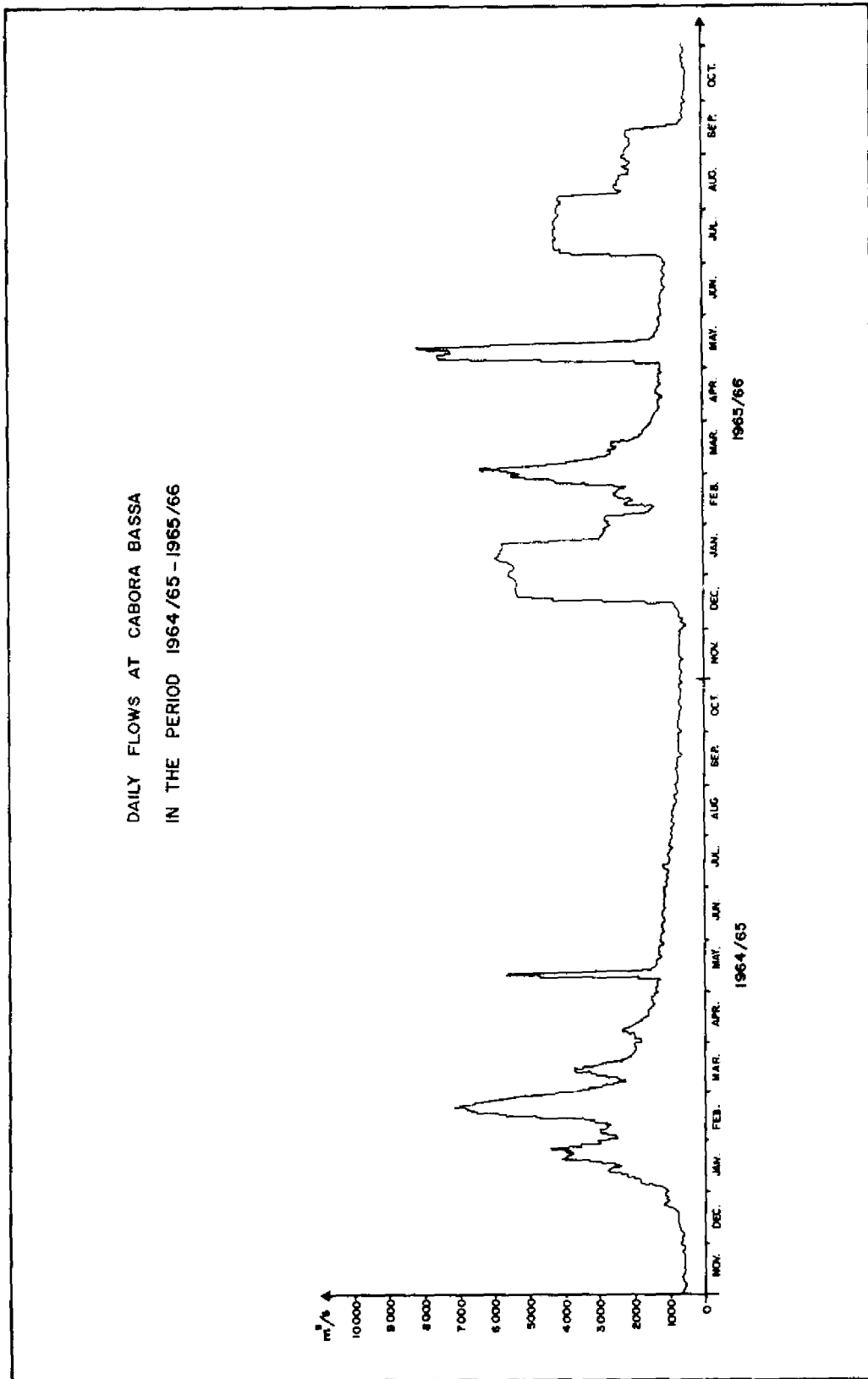
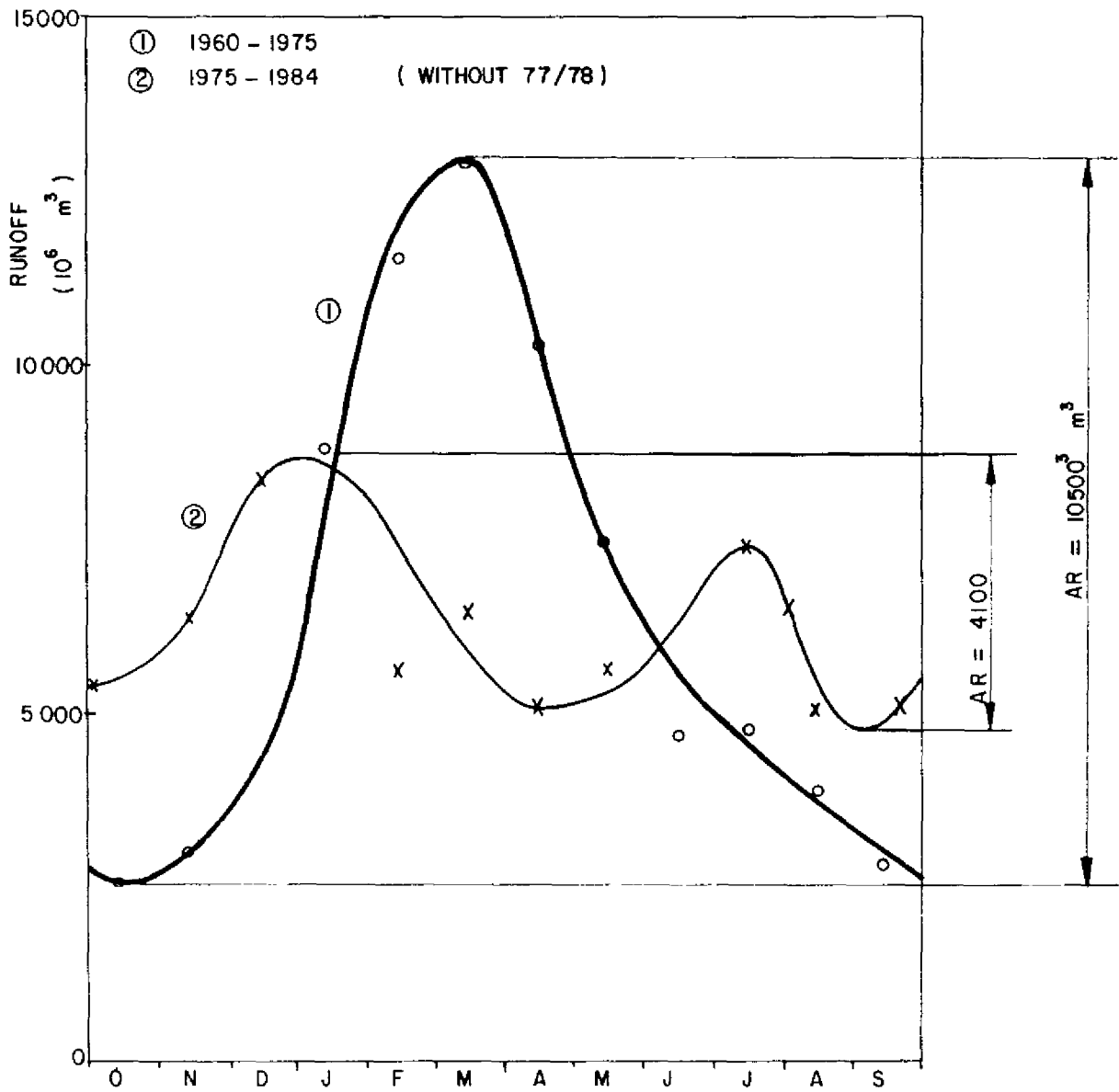


Figure 17.6: Monthly average runoff before and after the conclusion of Cabora Bassa



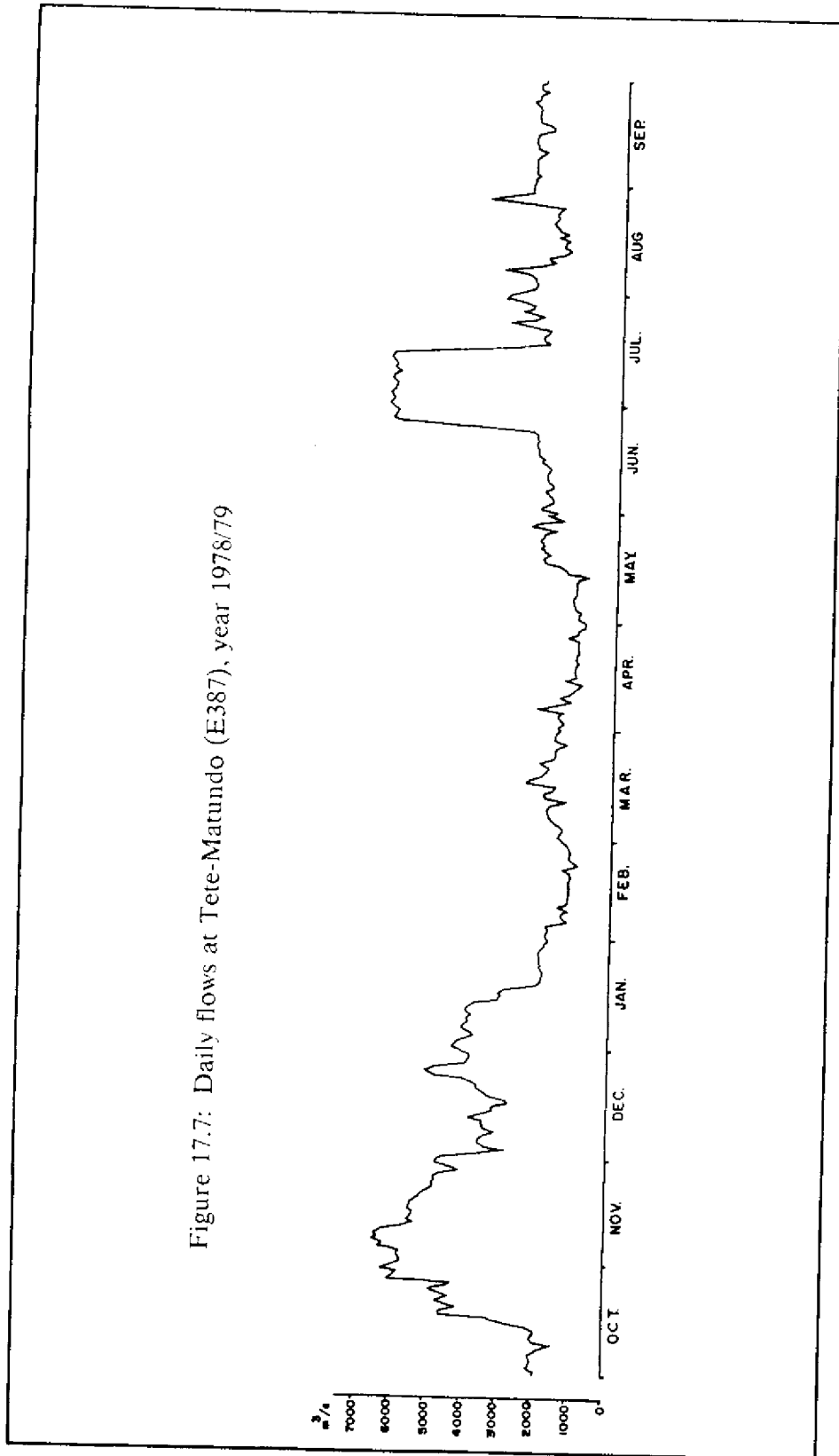
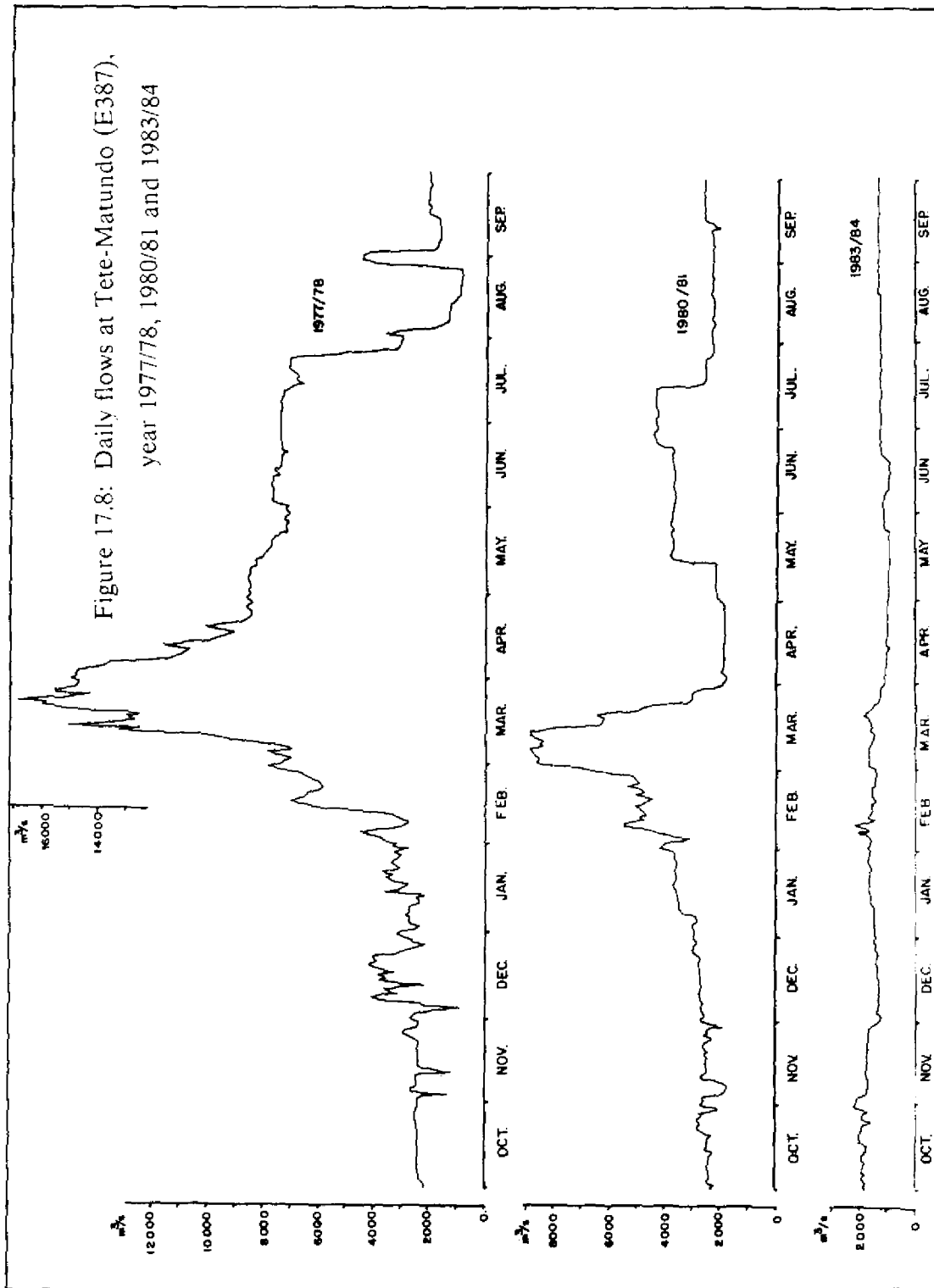


Figure 17.7: Daily flows at Tete-Matundo (E387), year 1978/79



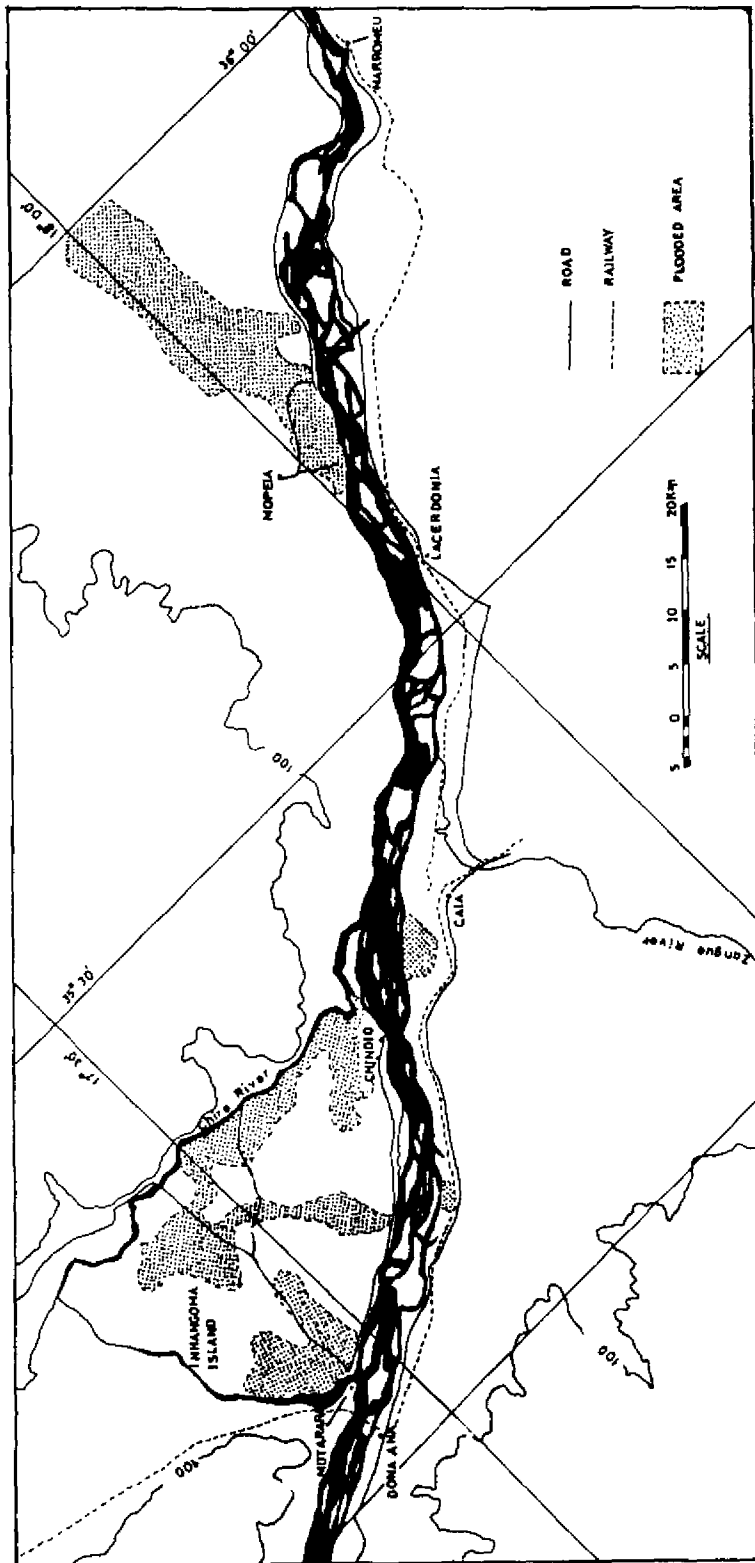


Figure 17.9: Estimated flooded area at a flow of 5 000 m³s⁻¹ at Lupata (Rendel, Palmer, Tritton, (1979))

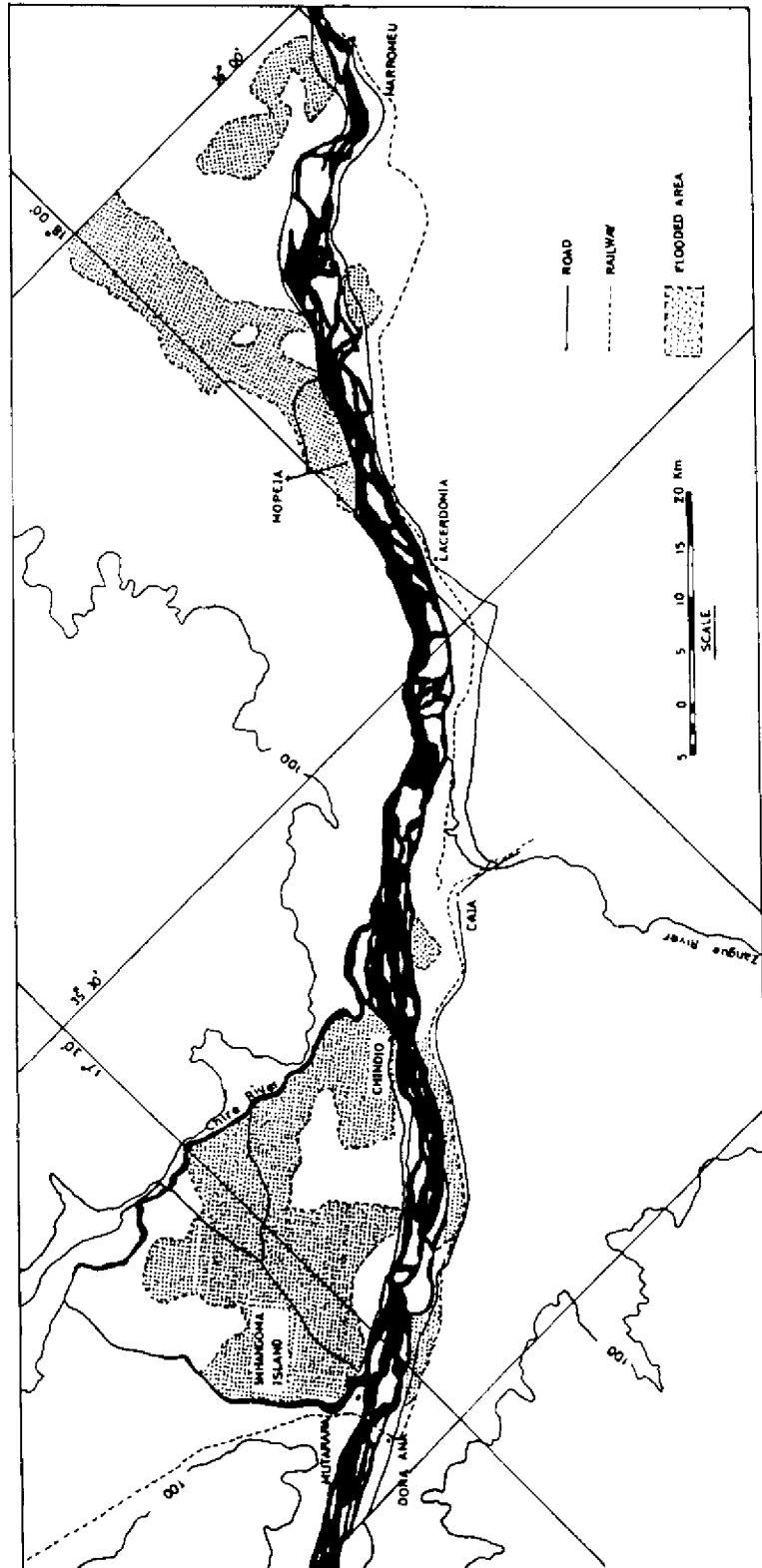


Figure 17.10: Estimated flooded area at a flow of 7 000 m³s⁻¹ at Lupata (Rendel, Palmer, Tritton, (1979))

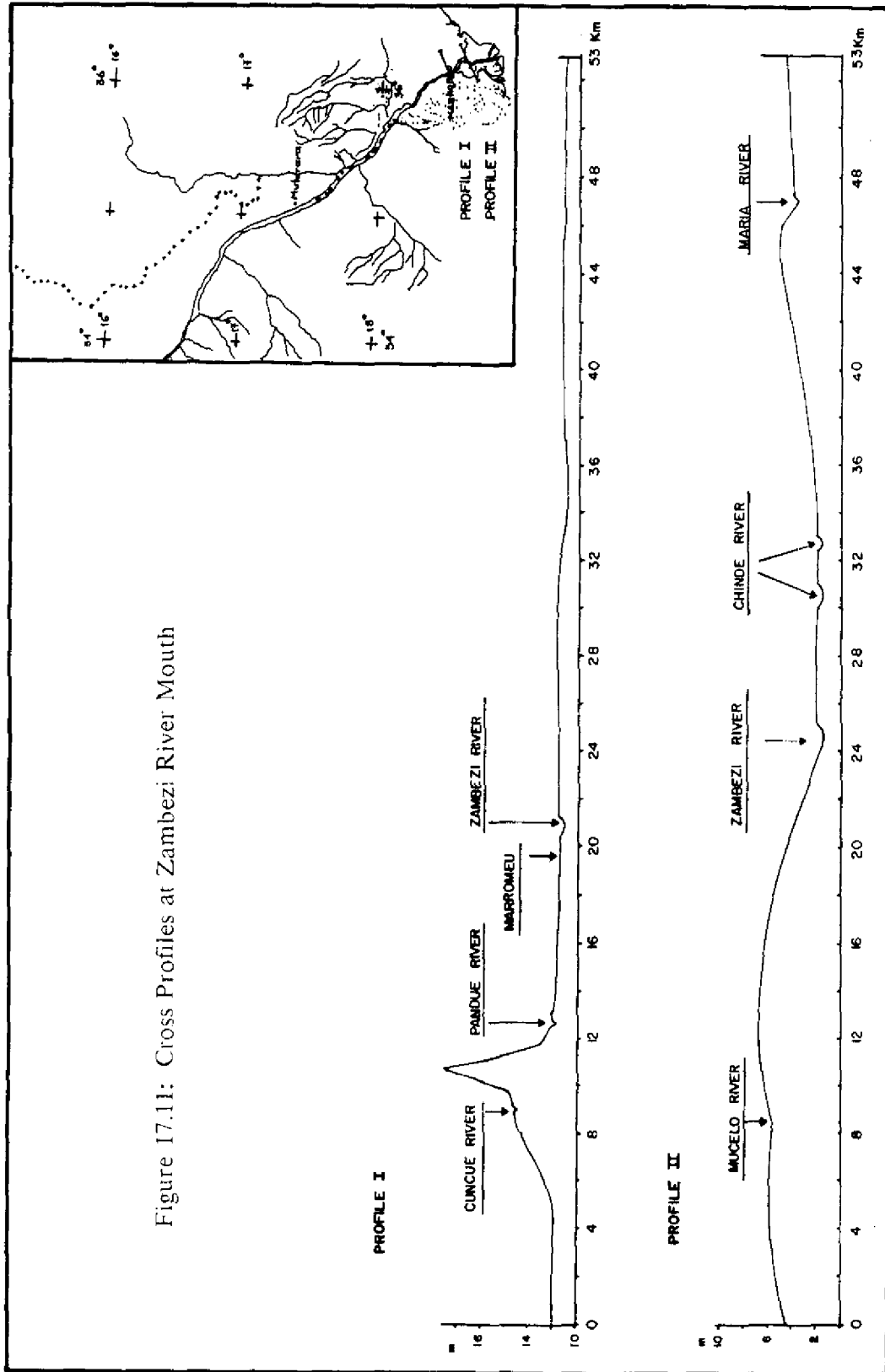
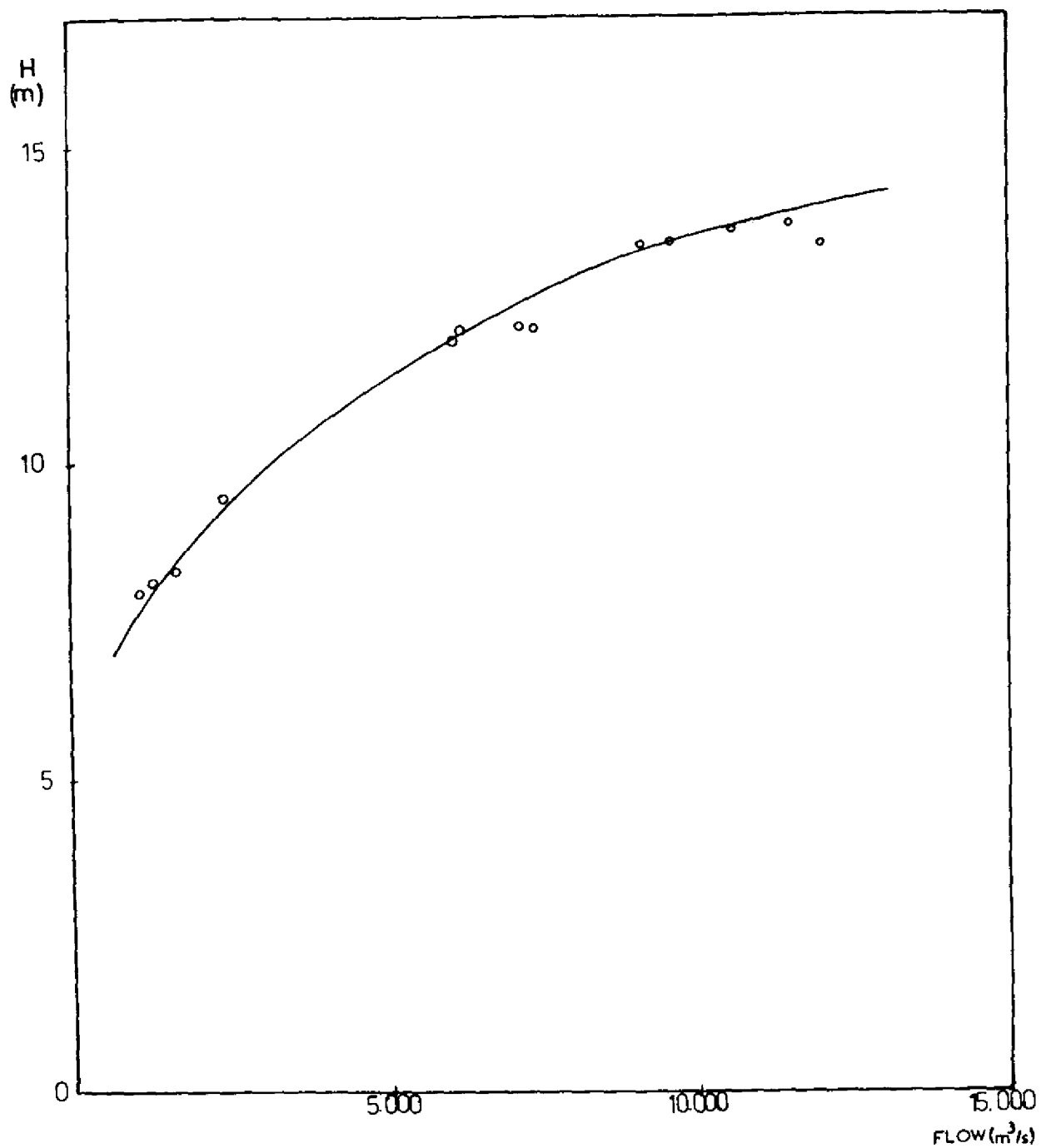


Figure 17.11: Cross Profiles at Zambezi River Mouth

Figure 17.12: Relationship between water level and flow e.g. at Marromeu station (1962/63).



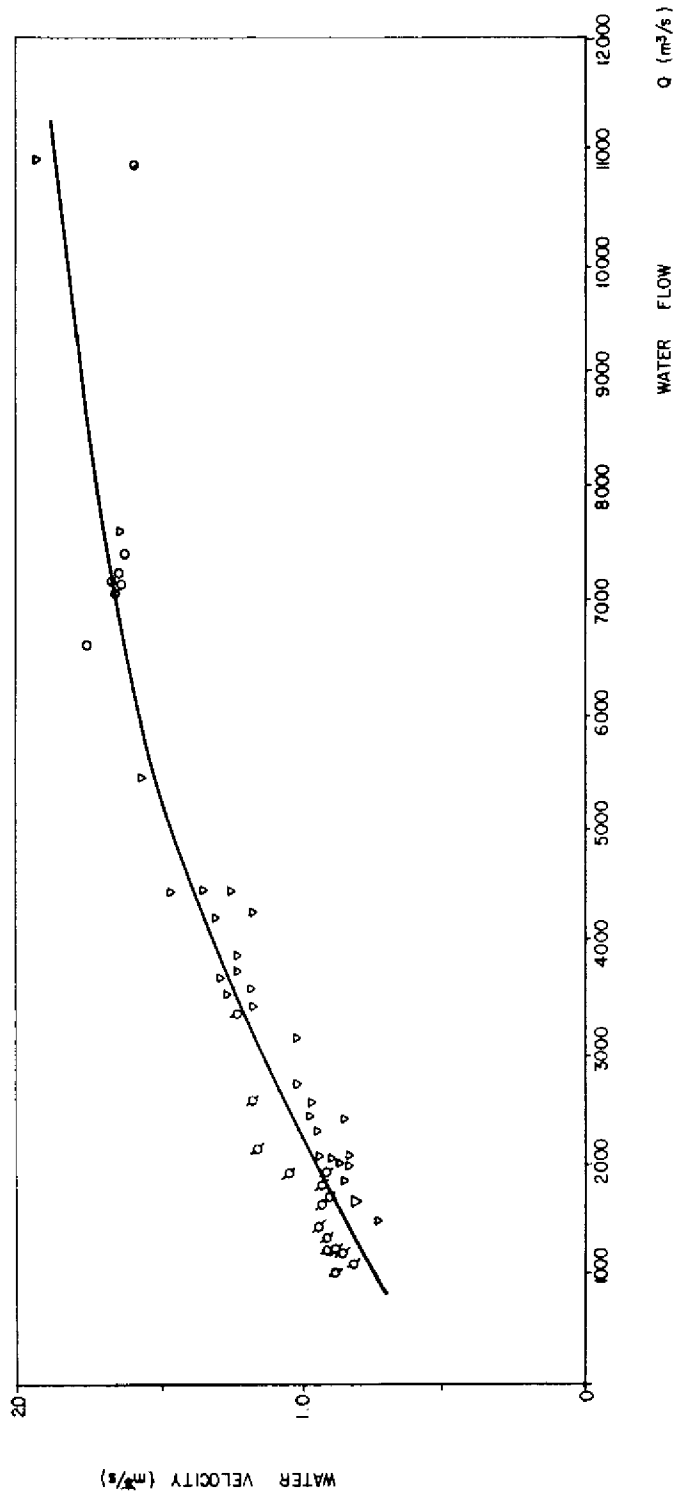
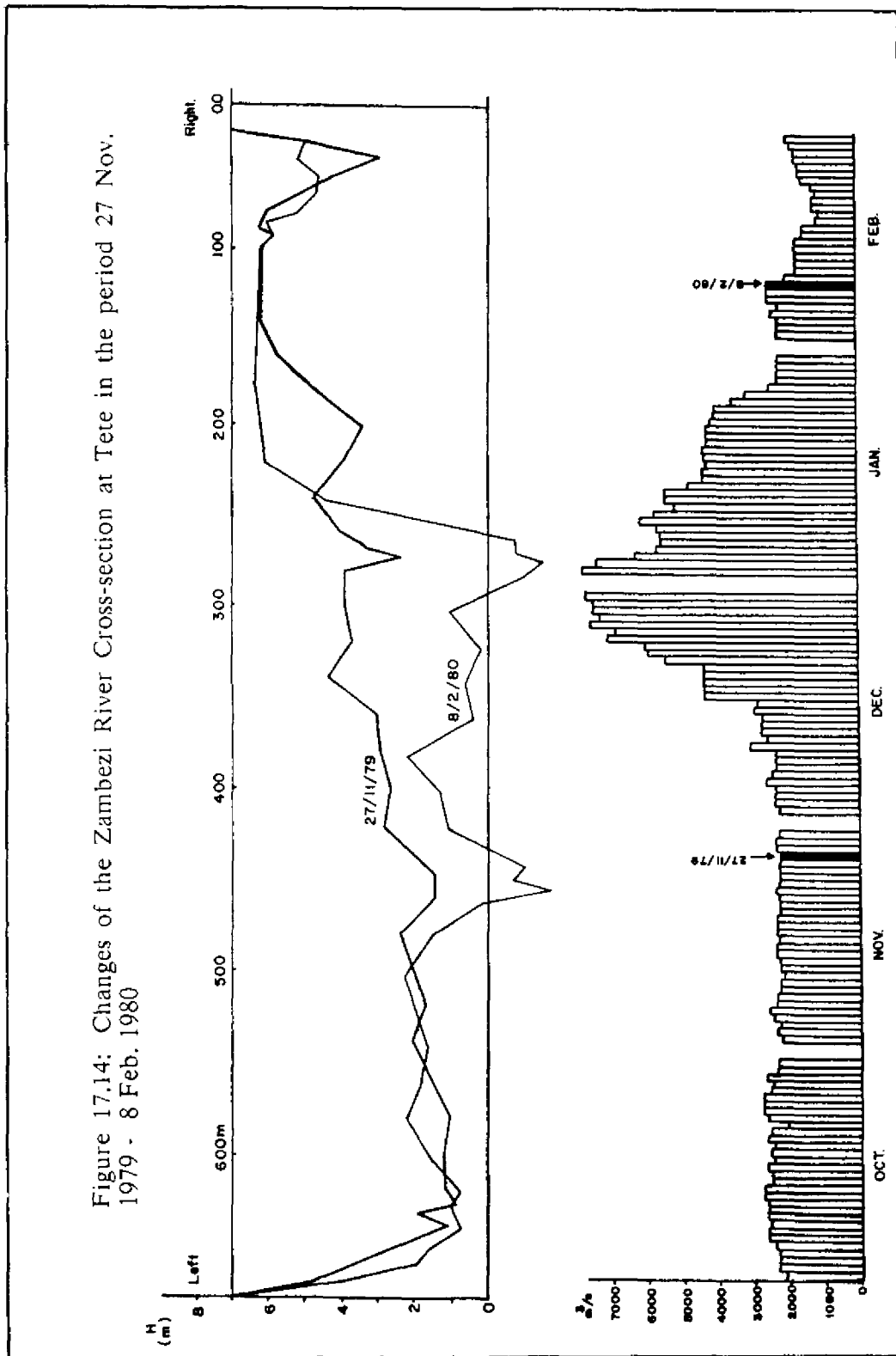
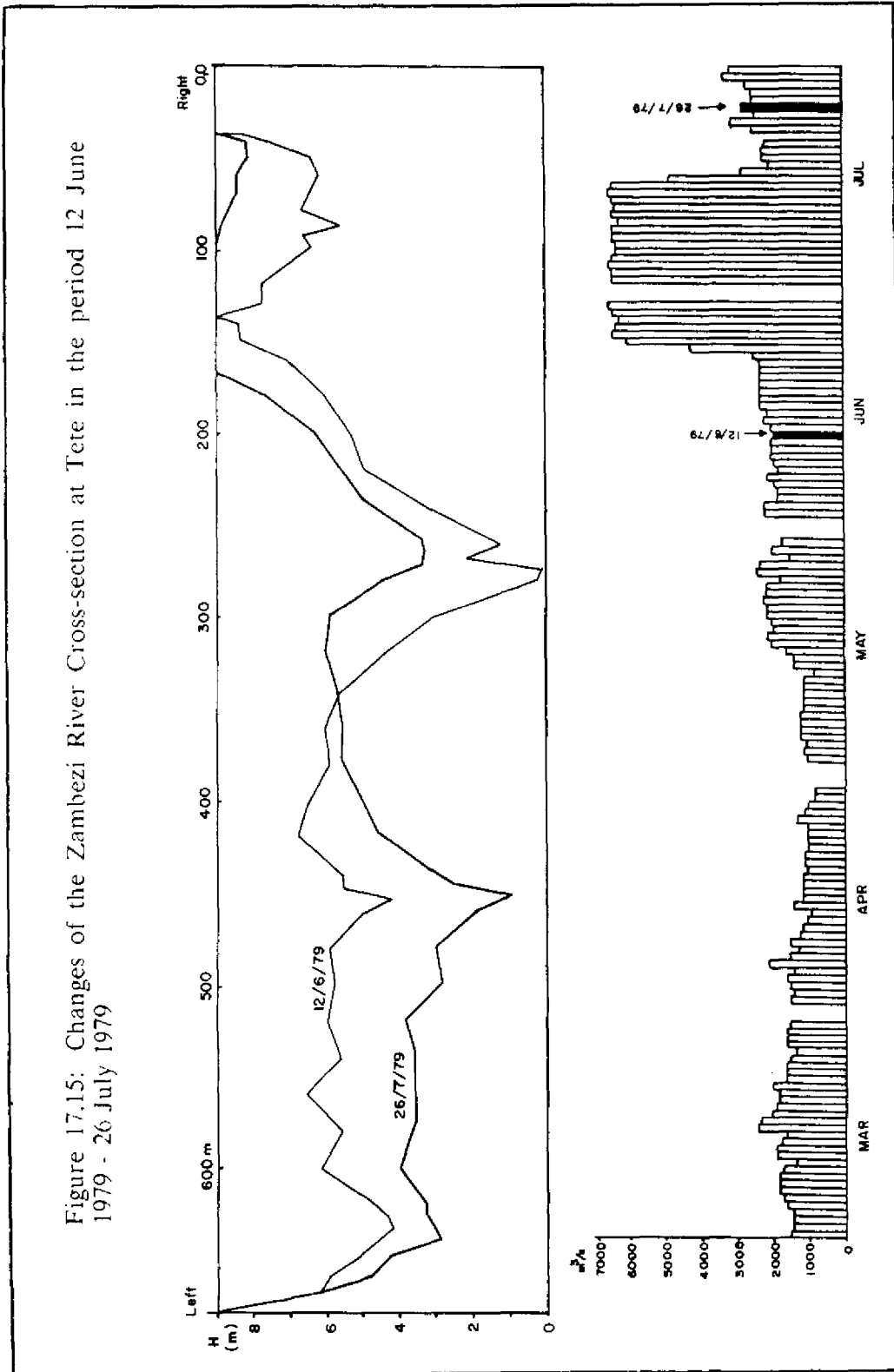
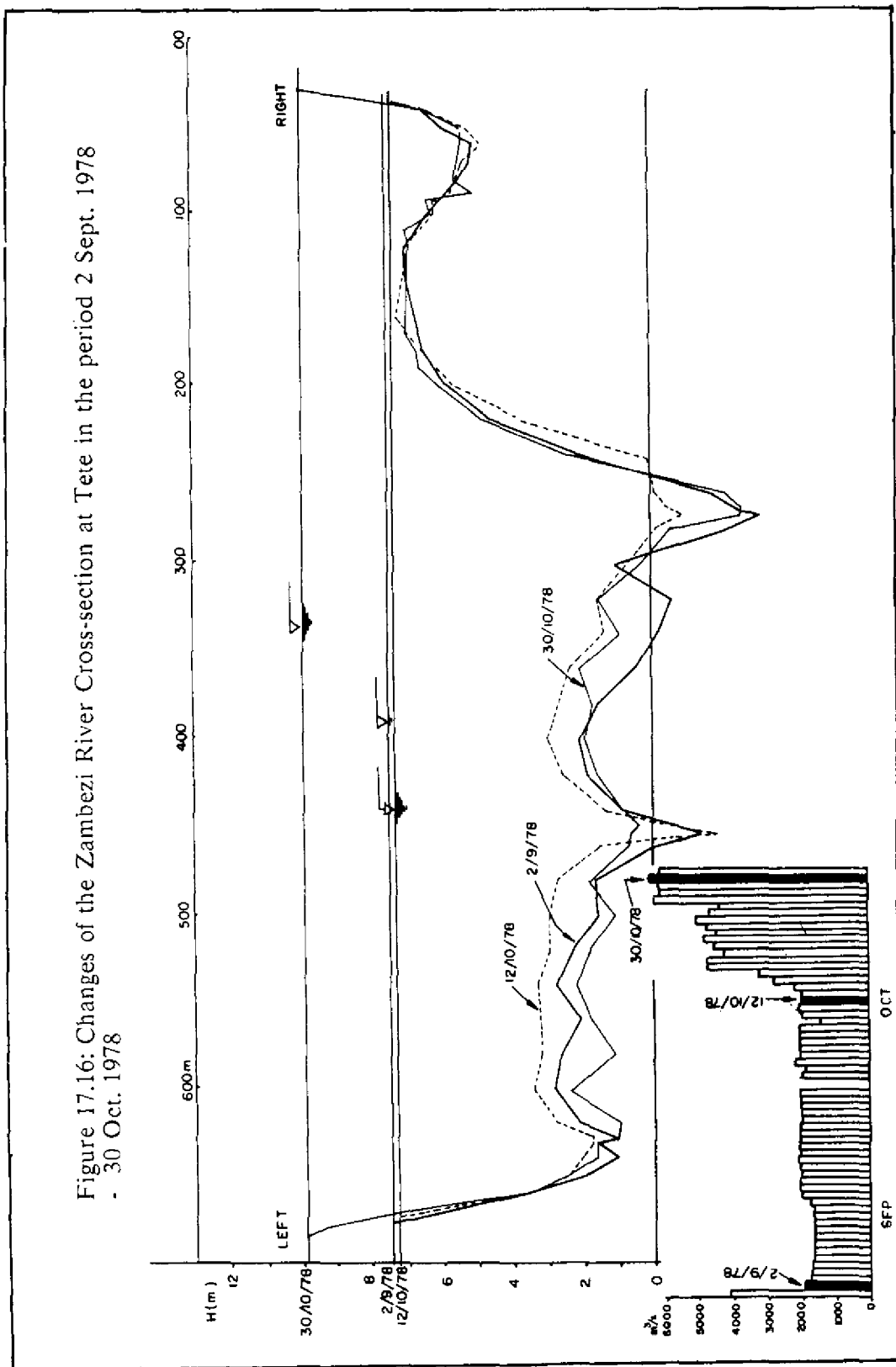


Figure 17.13: Relationship between water velocity and flow of the Zambezi River at Tete







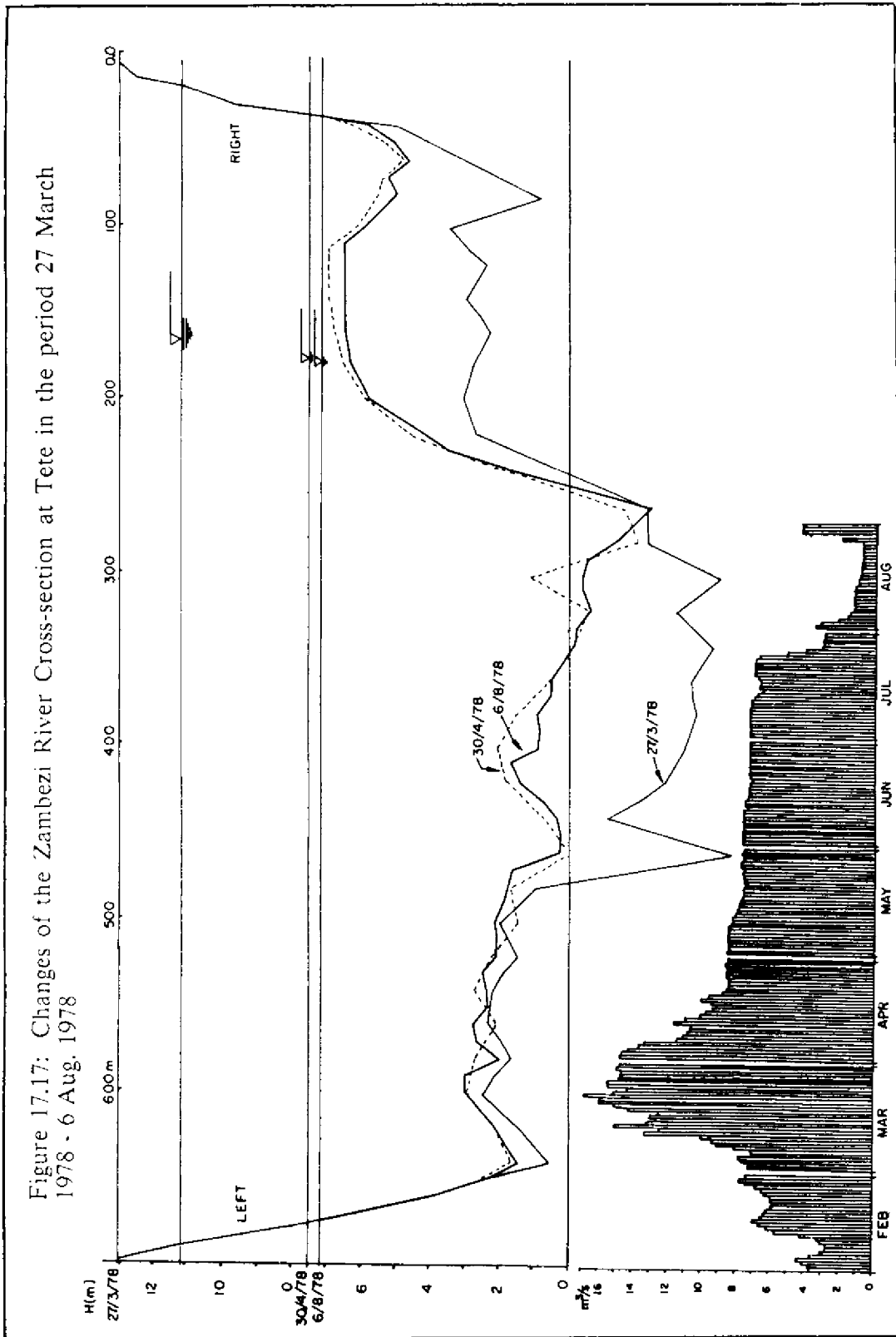


Figure 17.18: The profile of the Zambezi River Cross-section at Tete in the period Sept. 1978 - April 1986

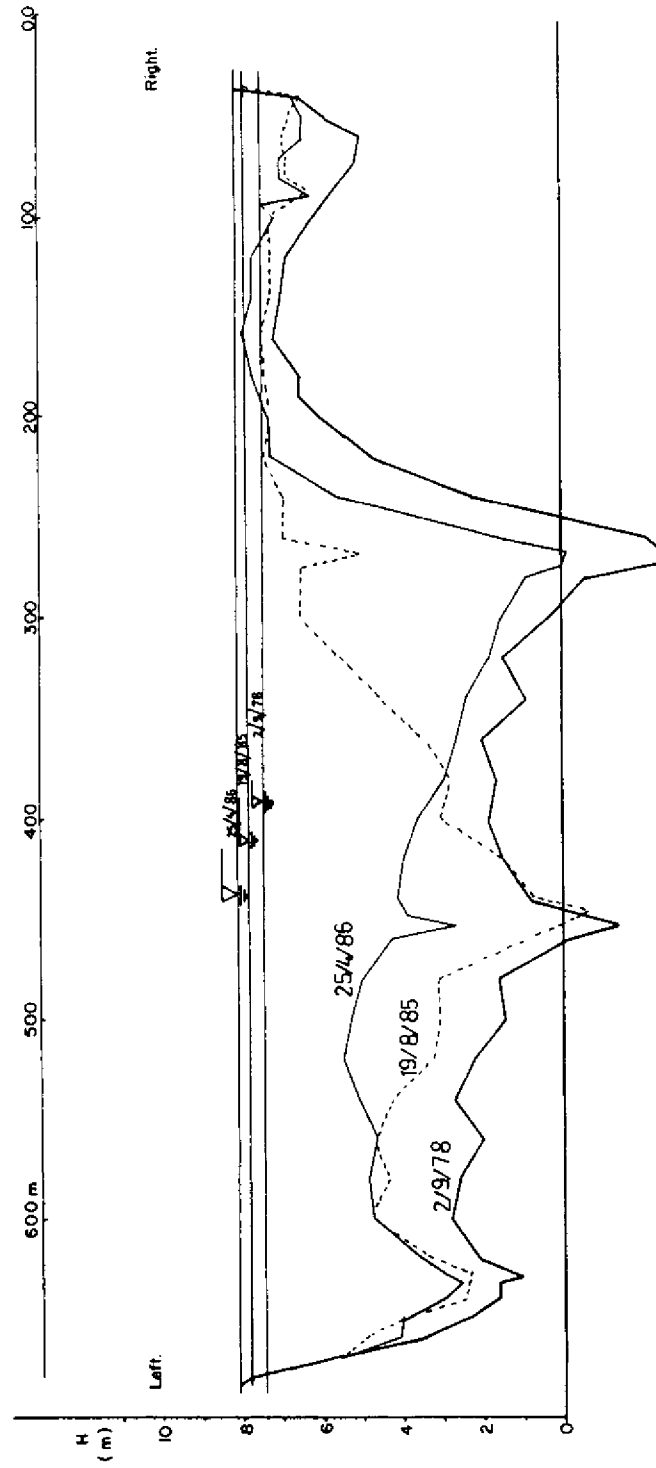
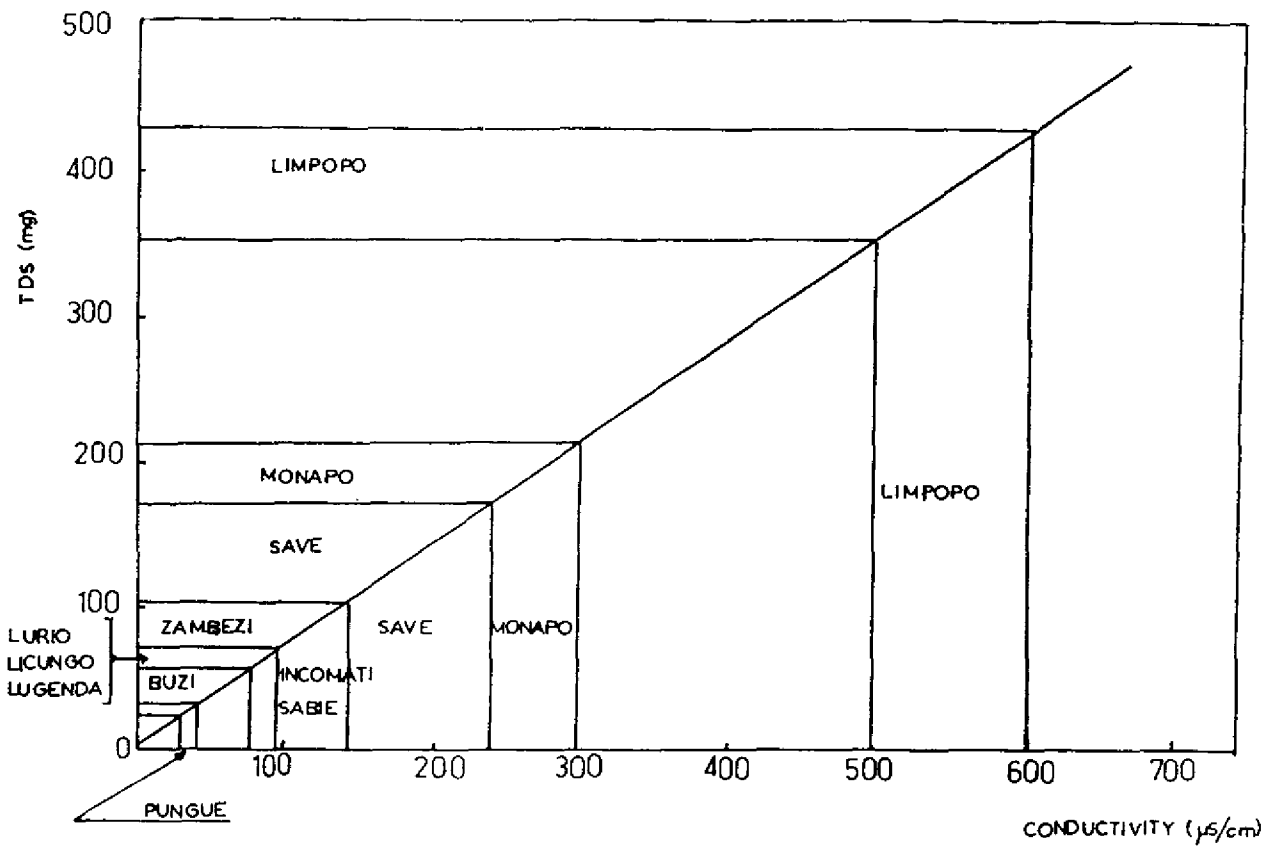


Figure 17.19: Salinity of the largest rivers of Mozambique



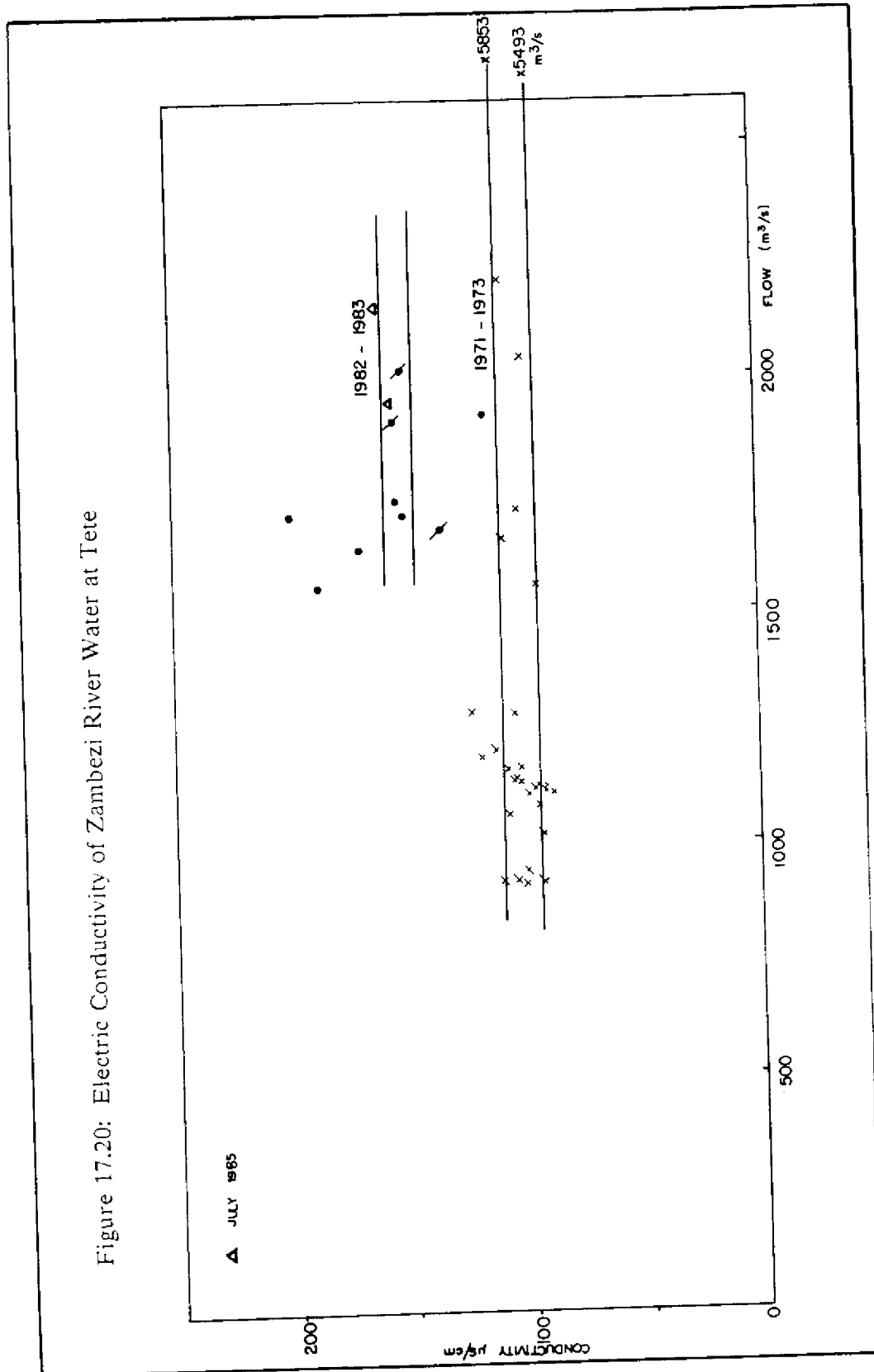
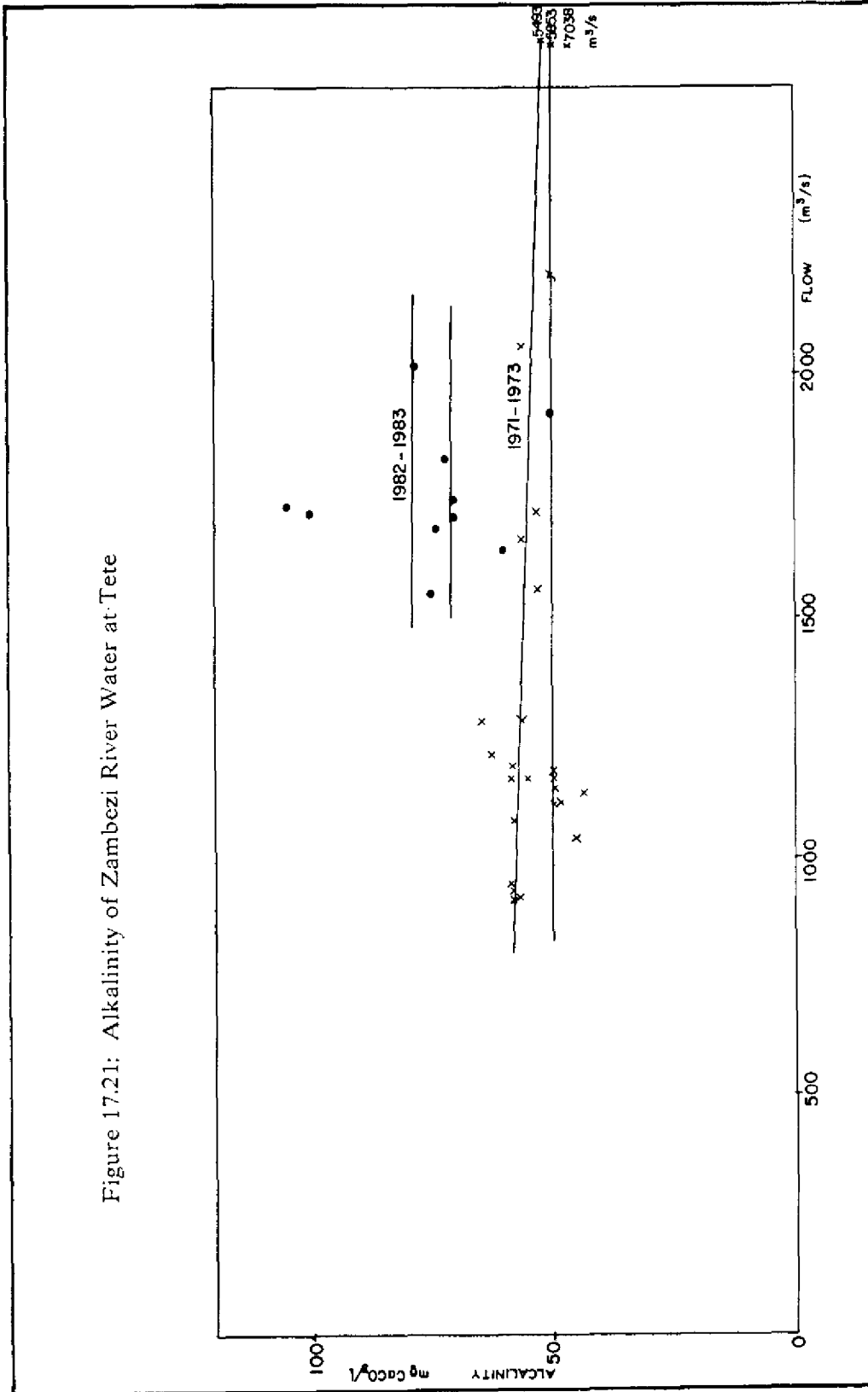


Figure 17.21: Alkalinity of Zambezi River Water at Tete



PAPER 18

ENVIRONMENTAL IMPACT ASSESSMENT OF THREE-GORGES PROJECT

*Guoping Wu*²⁰

This paper describes the principles and methods used for assessing the impacts on the environment of the proposed Three-Gorges Project, and the preliminary results.

The effects of the proposed projection the environment must be carefully examined before the project is finally approved to ensure that economic and social benefits are not incompatible with the negative environmental impacts. International standards should be applied and international experience should be made use of when a large project of this type is under consideration. The reservoir area, the backwater upstream and the river as far as the estuary should be considered as a whole. Multidisciplinary studies should be made in order to correctly evaluate impacts and effective measures should be considered for their mitigation and the elimination of any possible unavoidable adverse effects. Public opinion should be considered to be as important as experts' theories. On the basis of these principles, co-operative studies have been made, including field investigations, mathematical and physical models, remote sensing, analogies, threshold testing, cause-effect analysis, etc.. for assessing the impacts on the environment. The preliminary results indicate that the environmental impacts of the project would be limited.

The construction of the proposed Three-Gorges Project on the Yangtse River in the Hubei Province, is attracting the attention of numerous organizations and is considered to be the greatest project in China since the Great Wall. The primary objectives are fload control, power generation and the improvement of navigation conditions. Apart from the benefits of the project, its effects on the environment have been studied over a long period of time, and broadly discussed in China and elsewhere. This paper introduces the methodology and the personal opinion of the author on the environmental impacts of this large water project.

Historical Review of the Three-Gorges Project Environmental Study

The environmental problems such as sedimentation, geological problems such as induced seismicity, landslides and rock avalanches, and the recovery of fish as well as relocation and resettlement, were extensively studied between 1950 and 1970, although the term of "environmental problem" was not widely used at that time.

Since 1979, when "The Environmental Protection Law" was introduced, requiring that an environmental impact statement be prepared for large and medium-sized construction projects, more detailed work was carried out by a comprehensive study team consisting of more than 40 outstanding research institutes, universities and colleges and environmental

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protection agencies which led to the publication of "The Effects of the Three-Gorges Project on Environment" in 1983. An advisory board was then formed consisting of more than ten experts in environmental science and detailed research continued. In November 1984 and July 1985, enlarged consultations of the advisory board were held and the first draft and the revised draft of "The Environmental Impact Statement" were discussed. After each consultation, the drafts were supplemented and revised according to the suggestions of the board after which the statement was printed for public revision throughout the country.

Principles

The environmental impact of several hydroelectric projects have been assessed by the institution in charge of examining the environmental effects of water projects in the Yangtze basin. The effects on the environment of the Three-Gorges Project, however, are treated with special prudence, because it is the largest project undertaken. The main points considered are the following:

(1) Taking economic, social and environmental factors into account simultaneously the effects of the Project on the environment have been examined very prudently. National development requires more energy and safer surroundings for the human and industrial environment. It is clearly understood that economic development requires the sound management of natural resources and systematic investigation of its impacts on the environment. Although the economic benefits of flood control, power generation and improved navigation are not difficult to understand, the possible effects, especially those which could be adverse, must be carefully investigated. The effects are divided into two categories: natural and human environmental effects. They are then further divided into several components, parameters and measurements, in series. Finally, the combined effects are assessed and compared to the economic and social benefits. Only if the adverse effects on the environment are greatly outweighed by the benefits can the project be approved for construction.

It seems that the economic and social benefits are much greater than the environmental problems, mainly concerned with the relocation of inhabitants. Furthermore the abundance of clean energy in the reservoir area would change the economic structures and significantly improve the living conditions in an economically backward area.

(2) The Government decided that the Environmental Impact Statement, (EIS), a part of the feasibility study of the project, should correspond to the current international standards, and the main conclusions and context of the EIS were communicated to a number of foreign experts. Meanwhile, the experience gained from projects abroad was studied, making allowances for the specific nature of the Three-Gorges Project in order to arrive at sound conclusions. For example, the difference between the Three-Gorges Project and Aswan High Dam were considered when assessing the environmental effects. The ratio of annual mean inflow to the total capacity of the Three-Gorges reservoir is as large as 23 which is much greater than at Aswan. This, together with some other conditions makes for a more favourable situation at Three-Gorges as regards the environment. The ratio of installed capacity to reservoir area for several reservoirs in the world listed in Table 1 shows the Three-Gorges Project to have the most favourable ratio.

(3) Environmental studies must be carried out at every stage of the project. Usually a large-scale water project can be expected to have long-term environmental impacts. This is a unique characteristic of the effect of water projects on the environment. Because of this, the studies of environmental problems related to the projects should be planned in several

stages. During the assessment stage, co-ordinated with the feasibility study, the main objectives are to determine whether the project will exert any effects on the environment, how serious these might be and if they in any way threaten the feasibility of the project, and lastly, to determine possible alternatives and the cost of mitigating measures. The conclusions drawn at this stage will offer the decision-maker a reliable basis for taking a final decision. The end of this stage is by no means the end of the complete environmental study. At the design stage, related environmental facilities should be designed by suitable environmental planning of the affected areas. Moreover, during the construction stages of the main structure, protection measures will be provided. Environmental parameters should be monitored before, during and after the construction of the project and the results compared with the conclusions drawn at the assessment stage. When unfavourable environmental changes do occur, some modification of the operational pattern of the project may be introduced.

(4) The entire basin should be treated as a whole. The area upstream of the dam and the floodplain downstream, including the estuary, have been taken into account in the study of the effects of the Three-Gorges Project. Another feature of water projects concerning the environment is that although a project is located at one point on a river, its environmental impacts can extend over the whole basin. The proposed Three-Gorges dam site is located at Sandouping, 40 km upstream of Yichang and about 1 800 km from the river mouth. All the effects on different areas of the Yangtse floodplain have been identified and assessed. These areas are roughly the area upstream of the proposed reservoir, the reservoir area, the middle and lower reaches of the Yangtse River and finally the estuary. According to the assessment, the project would result in different effects in each of these areas. For instance, in the upstream area, the project might affect the fish population and species because of the lower flow velocity upstream of the dam. As far as the middle and lower reaches are concerned the project might not significantly affect the fish habitats because the hydrological regime would not greatly change. The monthly distribution of flow within the year would not change except that in the winter season the flow would slightly increase. The sensitive zone would be the area inundated by the reservoir. Because the reservoir is located in the gorge area, the effects of inundation would be very limited in comparison with other reservoirs in the world, especially, the lake-type reservoirs. After completion, the average width of the proposed reservoir will be 1 000 m, whilst the natural channel had a width of about 500 m.

(5) A multidisciplinary study is necessary. The main effect of water projects on the environment is due to changes in the hydrological regime. However, since changes in the hydrological regime will result in a series of other changes affecting the soil, the stability of reservoir shores, plants, animals, water chemistry, etc. the environmental aspects call for a multidisciplinary study so that precise and complete conclusions can be drawn.

The team assessing the environmental impacts of the Three-Gorges Project includes various specialities including geology, botany, zoology, fisheries, biology, ecology, water chemistry, public health, computer science, hydrology, sedimentation, agriculture and forestry. In the course of the assessment of this huge project, it was not easy to answer all facets of the questions raised concerning such a wide range of disciplines. For this reason a joint co-operative work team was organized. Furthermore, several institutions analyzed the same environmental parameters independently in order to assure the reliability of the conclusions. For example, three institutions were invited to take part in the study of schistosomiasis and malaria and their findings were compared and synthesized to form a solid basis for reliable conclusions.

(6) Discussions with other departments and institutions as well as with the general public are of vital importance. Sometimes disputes occur, but it is very useful to collect different opinions for an in-depth study in order to arrive at more convincing conclusions.

(7) Effective measures for mitigating and eliminating the unavoidable adverse effects should be proposed in the EIS. The assessment of environmental impacts is not sufficient to protect the environment. Measures must be proposed to eliminate or mitigate adverse impacts. The earlier the measures are taken, the less is the damage to the environment, so these measures should be proposed as early as possible and must be included in the EIS. Besides, the monitoring work must be continued in order to show whether these measures are correct and effective. For instance, methods for rescuing the Chinese sturgeon, a valuable migratory fish, have been studied for a long time. It was the major subject of debate in China before the construction of Gezhouba Dam, 27 km downstream of the proposed Three-Gorges Project. By taking a series of measures, mainly involving artificial breeding, the Chinese sturgeon still thrives in the damned Yangtse, but observation and studies continue in the hope of finding better solutions.

Methods used in the Assessment of the Three-Gorges Project

Environmental assessments and impact analyses are more an art than a science at present. There are no universally accepted procedures for conducting such studies. This is especially true for biological impact assessments. On the other hand, there are a lot of methods used for the assessment of environmental impacts nowadays, including averaging, checklists, clustering, commercial value, consensus techniques, cost-benefit analysis, decision trees, direct sensing or measurement, expert judgement, indices and indicators, mapping, matrices, overlay technique, simulation, threshold testing, etc. In order to select the methods for the assessment from among so many techniques, the following principles were considered.

1. **Comprehensiveness.** The method must embrace all significant alternatives, criteria aspects and major points of view. Without this approach, decisions are almost certain to be less than optimal and intellectually unacceptable.

2. **Workability.** The method must be simple enough to be learned and applied by a small staff with limited knowledge on a small budget in a short time.

3. **Portrayability.** The conclusions derived must lend themselves to summarization and visual presentation so as to instill perspective, understanding and confidence in the public and secure their participation.

4. **Expandability.** The method must permit initial screening of broad alternatives, and yet must be readily expandable to provide detailed focus on key aspects. Thus, the same method should permit either an overview analysis or a detailed examination.

5. **Explicitness of criteria.** The method must include an explicit statement of all relevant criteria, systematically arrayed and weighed to reflect their relative importance.

6. **Holism.** The method must reflect an understanding of the environmental socio-economic system as a whole and the major interrelationships among the various criteria.

7. Separation of effects. The method must reflect the changes that would occur in moving from a "without an alternative" to a "with the alternative" future and must allow for measuring or sensing the "distance" between sets of alternatives.

8. Commensurability. Various criteria are conventionally measured in a wide variety of objective and subjective units (monetary, biomass, recreation days, good-bad, jobs, etc.). It is highly desirable to employ a means of translating these ratings into commensurate units as a tool to facilitate comparison.

9. Data input. Ease of providing the required data input for a technique is a key criterion for the successful implementation of any model. Potentially excellent techniques may not be feasible because of the difficulty of data acquisition.

In the course of the environmental impact assessment of the Three-Gorges Project, some of these methods have been employed and a hierarchical system established in combination with other techniques and detailed studies. The environmental impact is divided into two environmental categories, the human and the natural. Each category is again divided into several components, and each component further divided into parameters which can be assessed by environmental measurement as follows:

Category	Component	Parameter	Measurement
Nature	Local Climate	Wind	Direction Mean Velocity Instantaneous Velocity etc.
			Fog Precipitation Atmospheric Temperature Humidity
	Water Quality	Nutrients etc.	
	Geology	Induced Seismicity, etc.	
	Sedimentation Aquatics Soil Etc.		
Human	Relocation		
	Public Health		
	Cultural Heritage		
	Etc.		

Many other techniques were used to obtain reliable results. Some of which are briefly described below.

Field investigation. This is the basic method for collecting accurate present data and forecasting future trends of environmental status. The data of almost all the environmental parameters have been investigated. Collecting the historical data and developing planning schemes are also included in this procedure for effective and accurate forecasting. Other purposes of field investigations include the validation of the information from remote sensing to test the results of mathematical models, specially designed experiments in the natural channel such as tracing the diffusion ability of pollutants.

Remote sensing. This technique is used for general surveys. A lot of information can be obtained from one air photo or satellite image and it is easy to digitize the necessary information for computer analysis later for various purposes. The largest scale of the air photos used was 1:10 000.

Models. Both mathematical and physical models have been used, mainly for sedimentation and pollution control. Mathematical models were also used for the study of local climate and the temperature of water released from the dam, etc.

Analogs. This involves the comparison of the impacts on the environment of the Three-Gorges Project with those of other completed projects. Some parameters were investigated by this method, but when using this method there must be a similarity of all surrounding conditions if successful conclusions are to be derived. These conditions may include every aspect of natural and social conditions, but since no two schemes are similar at least the most important factors must be comparable and the remaining differences taken fully into account when deriving conclusions.

Threshold. In the process of assessment, the threshold was used to test if the changes in environment would exceed certain values. It is important to ensure that the threshold values have a sound scientific basis. This method has been used in several instances, for instance the effect on fish breeding of the temperature of the water released from the dam.

Cause-effect analysis. This is very useful for describing some environmental parameters. In the case of the Three-Gorges Project it is used for some parameters, especially those concerning salt-water intrusion resulting from the construction of the reservoir.

It is worthwhile to indicate that these methods have been used in a cross-linked pattern. This means that more than one method was used for assessing a single environmental parameter. Besides, as mentioned above, each parameter was studied by more than one institution. This effectively ensured reliable conclusions for the assessment.

Brief Introduction to the Preliminary Results of the Environmental Impacts of the Three-Gorges Project

The benefits of this large-scale project are obvious. After completion it will have a significant effect on economic growth. The major environmental benefits are:

1. Alleviation of the threat of flooding, improvement of the productive environment and living conditions in the lake and floodplain areas of the middle and lower reaches of the Yangtse River.

2. Production of large quantities of clean energy, taking the place of coal-fired thermal power plants, avoiding accelerated environmental pollution, with only a relatively small area affected by submersion.

3. Improved navigability of different sections of the river, increase of streamflow during the dry season, resulting in an improvement of navigation conditions downstream of the dam and in the reservoir and backwater reach.

4. Enlargement of habitat for fish and vegetative growth, development of reservoir fisheries.

5. New scenic tourism and recreation facilities.

6. Improvement of water quality in the middle and lower reaches and at the mouth of the Yangtse River.

However, it is undeniable that the imposition of such an enormous construction on nature will alter the environment and bring about other changes, as has been the case of every large-scale water management project in the world. The inflow entering the reservoir is large and the reservoir capacity is comparatively small, with an overall capacity representing only 1/23 of the mean annual flow, and the reservoir is of the canyon type having a length of about 500 km and a width of about 1 km at the normal water level of 150 m. The length of the reservoir ranges from 180 to 480 km and the increase of water surface varies from 0.3 to 0.1 percent which is comparatively small and will not change the environment in the reservoir area significantly. Therefore, the influence of the project is not expected to be as big as is the case of most lake-type reservoirs. Moreover, it differs from Aswan in Egypt in the following ways:

1. The number of people to be moved is large. The problem of moving and relocating the people should be thoroughly planned in advance in order not only to improve the production and living conditions, but also to achieve the goal of improving the environment. In the situation and conditions holding in China, the task of relocating and resettling population is not as difficult as in Western countries.

2. The fish resources can be increased. The interruption of the migratory path for Chinese sturgeon should be compensated for by artificial breeding and release, operating in conjunction with the existing Gezhouba Project. The experience of the Gezhouba Project has revealed that the Chinese sturgeon can still grow and multiply below the dam, where it has established new spawning grounds.

3. Positive measures should be taken to prevent and cope with diseases which can affect public health. Special attention should be given to malaria eradication, although cases have decreased steadily since 1949. The sources of water snail upstream should be eradicated, although there are no water snails or schistosomiasis cases within the proposed reservoir area and its surroundings.

4. The quality of water in the proposed reservoir area is good. There are, however, some pollution zones along the banks of Chongqing, and it is urgent to control these sources.

5. Downstream from the dam, the range of variation of river water temperature is limited in the period from February to April, with a maximum value of 20°C. It will not affect agricultural production or the growth and multiplication of fish.

6. There will be no large-scale change in climate. The climate in some localized areas will change in a favorable direction.

Issues concerning sedimentation in the reservoir, erosion of the river channel below the dam, stability of reservoir banks, and the induced seismicity in the reservoir area, are discussed elsewhere.

Table 1: Ratio of installed capacity to submergence area of some typical hydropower schemes

Project	Country	Rated Capacity (GW)	Normal Reservoir Area (ha)	Ratio (kW ha ⁻¹)
Three-Gorges	China	13.0	57 200	227
Paulo Alfonso	Brazil	1.3	7 520	173
Sayanskaya	USSR	6.4	80 000	80
Churchill Falls	Canada	5.2	66 500	78
Itaipu	Brazil/Paraguay	10.5	135 000	78
Grand Coulee	USA	2.0	32 400	62
Jupia	Brazil	1.4	33 300	42
Tucuri	Brazil	6.5	216 000	30
Ilha Solteira	Brazil	3.2	120 000	27
Guri	Venezuela	6.0	328 000	18
Furnas	Brazil	1.2	135 000	9
Aswan High	Egypt	2.1	400 000	5
Volta	Ghana	0.83	248 200	3
Brokoponda	Suriname	0.3	150 000	2

PAPER 19

ENVIRONMENTAL AND SOCIAL CONFLICTS ASSOCIATED WITH THE DEVELOPMENT OF WATER RESOURCES IN SOME ARID AREAS IN NORTHEAST AFRICA AND ARABIA

*Abdu A. Shata*²¹

1. Introduction

In arid areas, it can be observed that urban, rural and industrial developments are principally located in the lowland areas. In terms of geomorphology and referring to development projects carried out in NE Africa and the Arabian Peninsula during the past two decades, such lowland areas comprise the following (Figure 1):

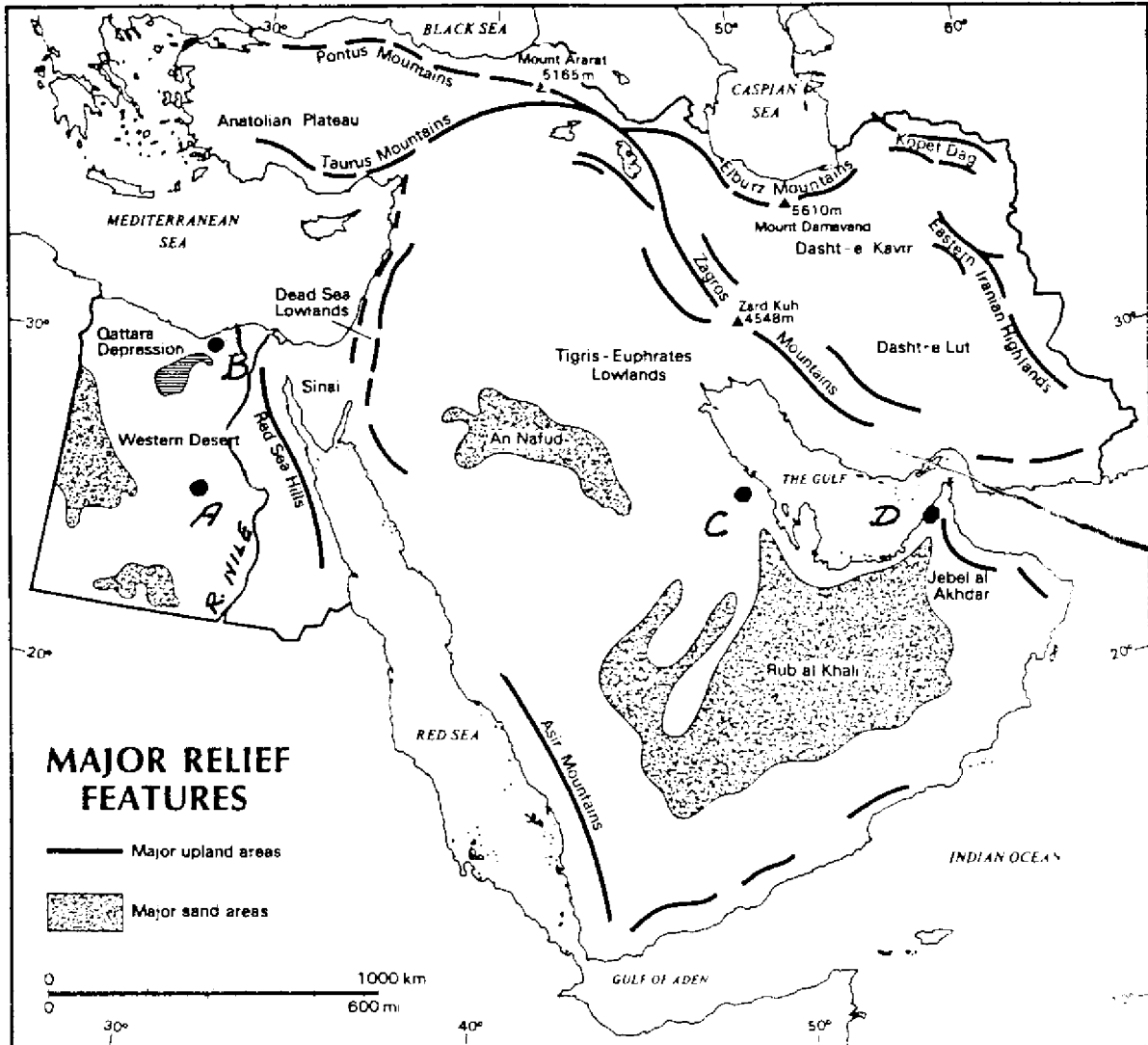
- the fluvial plains; best represented by the river flood plains, e.g. the downstream portion of the River Nile in Egypt or by the bajadas at the foot of mountain masses, e.g. the bajadas bordering the Oman Mountains in Eastern Arabia. (Jebel Al Akhdar).
- the structural plains; coinciding usually with downwarp zones and best represented by the Nubian Plain in South Egypt and North Sudan and by the El Ehsaa Plain in Eastern Arabia.
- the littoral plain; best represented by the Southern Mediterranean Littoral Zone in Egypt and the Western Foreshore Plain of the Gulf.

In the following pages, examples of the environmental and social conflicts associated with the establishment of ambitious land reclamation projects in arid lowland areas, will be presented. Emphasis will be given to the following projects:

- the New Valley Land Reclamation Project in the desert west of the Nile in Egypt.
- the projects for agricultural expansion in the Western and Southern Foreshore Plains of the Gulf.
- the projects for agricultural expansion in the old fluvial and foreshore plains west of the Nile Delta in Egypt.

²¹ *Desert Institute, Cairo, Egypt*

Figure 19.1: Selected Major Water Projects

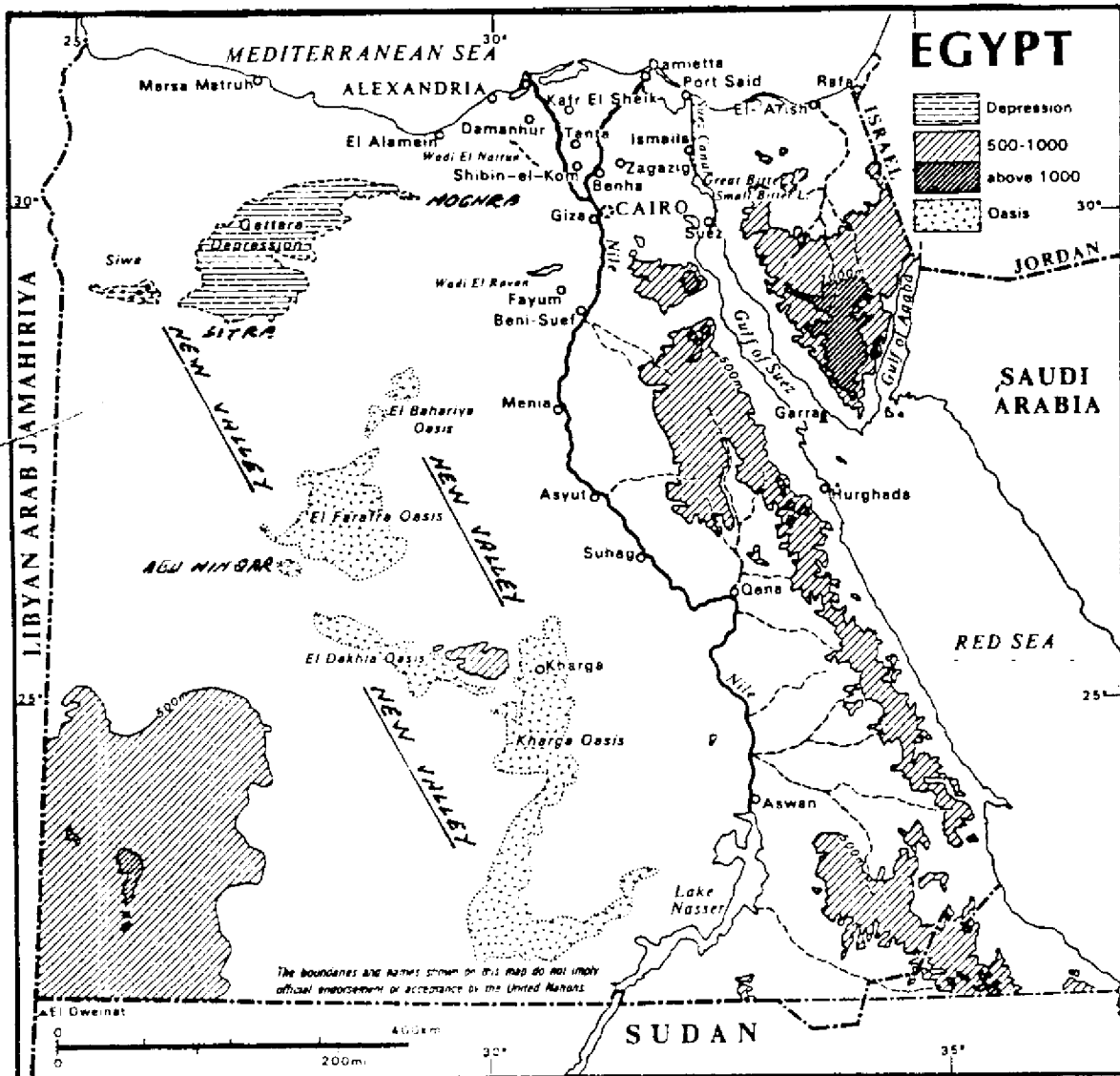


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SELECTED MAJOR WATER PROJECTS

- A - NEW VALLEY
- B - WEST NILE DELTA
- C - AL EHSAA - HARADH
- D - DHAYD - RAS AL KHAYMAH

Figure 19.2 New Valley Land Reclamation Project



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2. The New Valley Project

The new Valley Project was planned to cover the chain of morphotectonic depressions in the desert west of the Nile in Egypt (Figure 2). Within such depressions scattered living and dead oases are found which depend for their supply of water on the natural springs as well as shallow and deep wells. The oases generally occupy the lowest portions of the depression areas and display classical examples of pediment geomorphology. The surface is principally underlain by unconsolidated lacustrine deposits (Quaternary), occasionally covered by shifting sands and wet sabkhas, and the ground elevation is generally below +100m (Ali Dakhla Al Farafra, Al Bahariya) and is, in places, close to sea level or even below it (Al Kharga, Siwa). The population of the oases, before the start of the New Valley Project at the end of 1950's was of the order to 100 000 and there was continuous migration in the direction of the fertile land in the Old Valley. After 1960 migration from the oases almost stopped and the rise in the population exceeds 30 percent. The increase resulted not only from the returning emigrants but also from the influx of labourers and technicians involved in the reclamation of the new land.

In the New Valley area, the strata of hydrogeological interest are composed of a sandstone complex (Paleozoic-Mesozoic), commonly referred to as the Nubian Sandstone. This sandstone complex has a thickness varying from less than 500 m to more than 3 000 m and rests on hard basement rocks (Figure 3). The sandstone is, in places, overlain by carbonate rocks, which display Karst features locally and are recharged, essentially, by upward leakage from the underlying sandstone aquifer. The sandstone complex, which extends into Libya, Sudan and Chad, comprises a multi-layered artesian basin, where huge groundwater storage reserves (21×10^{18} to 234×10^{12} m³) were accumulated, *in situ*, principally during the pluvials of the Quaternary (Shata, 1982). When exploiting the groundwater in the sandstone aquifer on a large scale during the 1950's and 1960's, various problems were met. Concerning such problems reference will be made to those caused by:

- the reduction of the pressure in almost all the water-bearing layers; a phenomenon which is particularly manifested in the deep layers. This implies a constant lowering of the piezometric groundwater level and consequently the amount of water abstracted. It is anticipated that by the end of this century, the level of water will drop, locally, by an amount exceeding 100 m.
- the severe corrosion of the steel used in the casing of the wells drilled, because of the high content of CO₂ and H₂ S in the groundwater; a phenomenon which accounts for the collapse of the wells and consequently results in a severe reduction of the amount of water produced.

Although the land reclamation involved with considerable expense and energy during the 1960's (50 000 ha extended to 100 000 ha), the problems of water development, in addition to other problems of land utilization (discussed later), the outcome of the New Valley Project was really disappointing and by the mid-1970's there was much uncertainty about the project's future (Mayer, 1980). During the early 1980's a comprehensive re-evaluation of the project was made - Pacer-Euroconsult, 1983 (Tables 1, 2 and 3). At present the progress of work is rather slow and with the exception of local activities in Farafra Oasis, the land reclamation in the Western Desert has come to a standstill.

In addition to the problems caused by the inadequate plans for the intensive development of the fossil groundwater of the Nubian Sandstone basin, serious problems are

caused by salinization and paludification, due to inadequate water management. Without going into details such problems result either from the flow of excess groundwater or the inefficiency of the drainage systems in the irrigated areas. As mentioned above, the areas occupied by the oases and the areas selected for reclamation fall, essentially, within the lowest topographical portions of the morphotectonic depressions (pediments). This allows for the accumulation of the water naturally flowing from the springs and the drilled wells. The continuous accumulation of the subterranean water results in the formation of dry and wet sabkhas (in the case of Siwa Oasis, the daily outflow of water from about 200 springs has been estimated as about 400 000 m³). Because the topography of the pediments is not even, islands of cultivated areas, essentially with palm groves, usually outcrop amidst the sabkhas. When the level of the accumulated water exceeds the ground level of the islands, the vegetation disappears and the oases are lost (Qaret Umm Al Saghir located in the western corner of the Qattara Depression is a typical vanishing oasis, whereas Moghra oases on the opposite side of that depression and the group of oases on the southern side, namely Sitra, Arag, Al Bahrein and Nuwemisa are examples of dead oases). The application of basin irrigation in both the old and the new land areas creates similar problems in almost all cases, where the drainage systems are not efficient.

Because the groundwater in the Nubian Sandstone Basin is the backbone of the development plans in the New Valley, all efforts are being directed to improve knowledge of its occurrence and the most economic utilization. Such efforts include:

- attempts made to simulate the groundwater conditions in various localities by analogue and digital computer models (Figure 4).
- cooperation with adjacent countries using the same type of water (a good example is the joint U.N. project between Egypt and Sudan).
- construction of night reservoirs for the storage of flowing water when not needed for irrigation purposes.
- improving the drainage system in the cultivated areas. In such areas deeper channels are dug and drainage pipes are laid as a means of lowering the groundwater table. Pumping stations are also established to raise the drainage water to areas away from the cultivated areas, in which the water subsequently evaporates.
- improving the irrigation techniques by using sprinkler and drip systems.

Figure 19.4 Groundwater Model Nodal Network

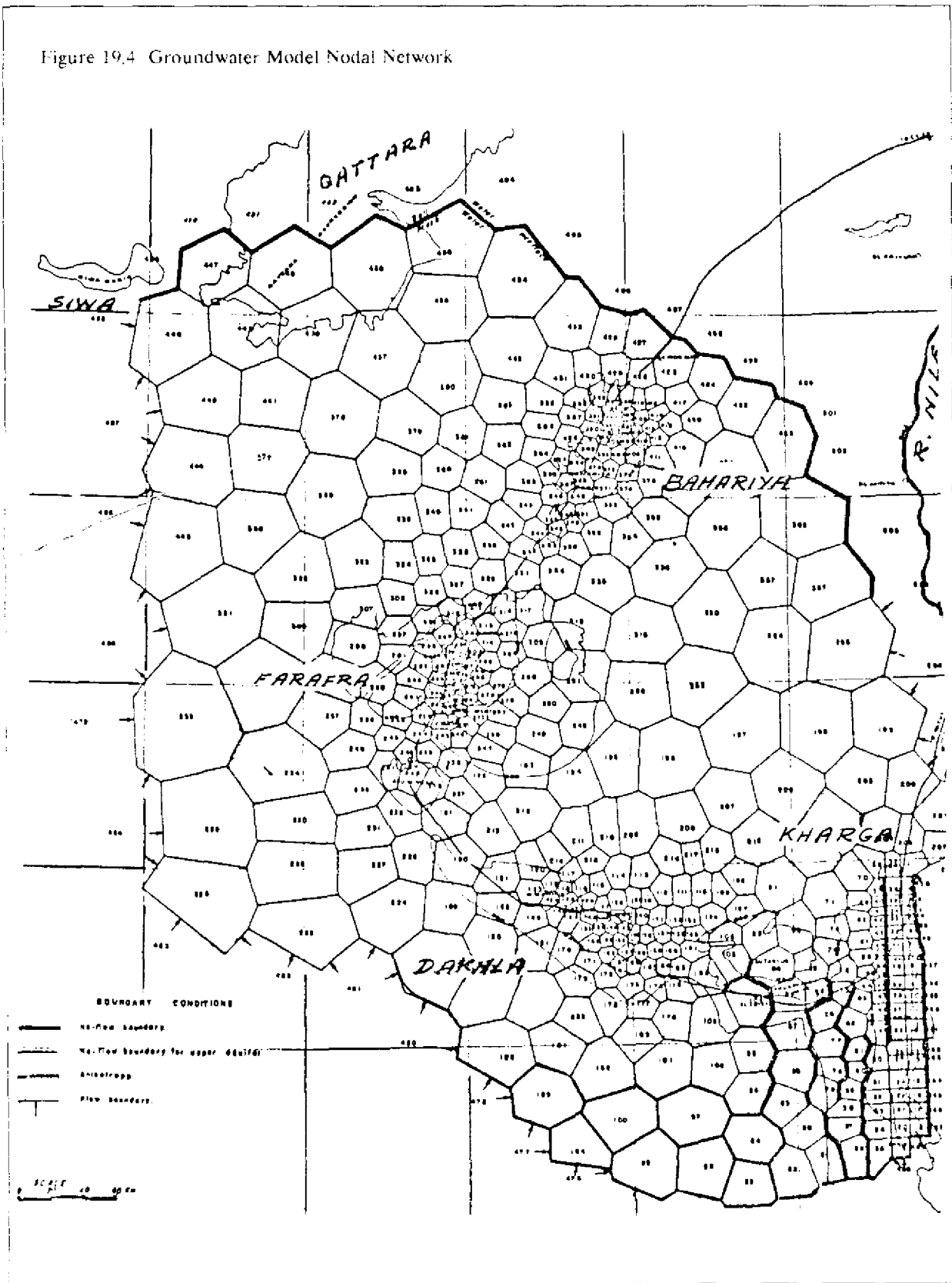


Table 1 - Annual water withdrawals from shallow and deep aquifer as entered in the planning run of the groundwater model (Mm³)

Year	S/D ⁽¹⁾	Kharga Zayat	El Tartur	Abu	Dakhla Mawhoob	West Muncar	Abu fra	Fara- wein	Kara- riya	Baha-	Total
1980	S	14.7	-	-	51.2	1.1	-	0.2	-	15.9	83.1
	D	75.0		111.0	36.3	15.0	1.1	-	16.3	254.7	
1985	S	15.4	7.1	2.7	65.3	1.1	-	40.1	-	31.1	162.8
	D	76.7	7.1	2.7	160.6	36.3	15.0	1.1	-	23.6	323.1
1990	S	16.0	7.1	5.4	79.4	1.1	-	80.1	-	46.3	235.4
	D	81.6	7.1	5.4	210.2	36.3	15.0	1.1	-	31.0	387.7
1995	S	17.0	7.1	8.2	93.5	1.1	26.0	80.1	-	61.5	294.5
	D	86.5	7.1	8.2	259.7	36.3	15.0	1.1	-	38.3	452.2
2000	S	18.0	7.1	10.9	107.6	1.2	32.0	80.2	22.4	76.7	356.1
	D	91.4	7.1	10.9	309.3	36.3	15.0	1.1	169.6	43.7	686.4

(¹) S = Shallow aquifer; D = Deep aquifer

If such efforts proved useful in many cases, numerous problems still remain to be solved. Such problems, however, can be considered minor in view of the dense population in the Nile Valley. Through the application of modern techniques of water management, land utilization and desertification control it will be possible to enhance the environmental status of the New Valley.

Before the end of this century it can become an important spillway for the increasing population of the Old Valley.

3. The Foreshore Plains of the Gulf

From the geomorphological point of view, such plains are classified as follows:

- the structural plains developed on the foreland side of the Arabian Platform as well as the western downwrap zone adjacent to the Oman Mountains. Such plains are essentially invaded by the shifting sands of Rub Al Khali in the south and Al Dahna in the north.
- the western bajadas at the foot slopes of the Oman Mountains and extending from Al Dhadriah in the south to Al Hamrariah in the north and passing through Al Jaww, Madam, Dhayd and Jiri. Such bajadas are principally occupied by coalescing alluvial fans and the surface is crossed by wadis directed westward.
- the coastal plains, dominantly occupied by sabkhas, stranded calcareous ridges and occasional outcrops of Tertiary limestone and evaporites.

Table 2 - Present and future land use (ha) ⁽¹⁾

Area	Present land use	Possible expansion	Future land use
Kharga	2 430	-	2 425
El Zayat	250 ⁽²⁾	375	625
Dakhia	5 370	7 250	12 625
West Mawhoob	825	500	1 325
Abu Muncar	250 ⁽³⁾	1 125	1 375
Farafar	65	3 125	3 200
Karawein	-	7 500	7 500
Bahariya	1 375	5 125	6 500
Total	10 565	25 000	35 575

⁽¹⁾ Source: NVDA

⁽²⁾ 7.5 ha only presently under cultivation

⁽³⁾ 168 ha only presently under cultivation

In the foreshore plains of the Gulf, there has been a conspicuous effort, during the past two decades, by the government towards better social and economic conditions. This has resulted in a rapidly increasing demand for groundwater, which is the only source of water supply. In the foreshore plains the groundwater exploration and development, financed by the income from oil production, have reached spectacular levels, which are expected to add to the problems of the environment, in some localities, threatened by the shifting sands, salinization and paludification (Abu Dhabi). In presenting the environmental problems of the foreshore plains, the discussion will be focussed on two areas (Figure 5):

E) Ehsaa-Haradh in East Saudi Arabia,
Dhyd-Ras AlKhaymah in Northern United Arab Emirates.

In the El Ehsaa-Haradh area, the strata of hydrogeological interest are found in the Cenozoic and are essentially developed into fissured carbonates. On top of the various anticlinal ridges, which cross that area (best represented by Haradh), the Cenozoic aquifers become hydraulically connected, through faulting and unconformity surfaces, with the underlying Mesozoic clastic aquifers. From top to base these strata comprise (Nori, 1983):

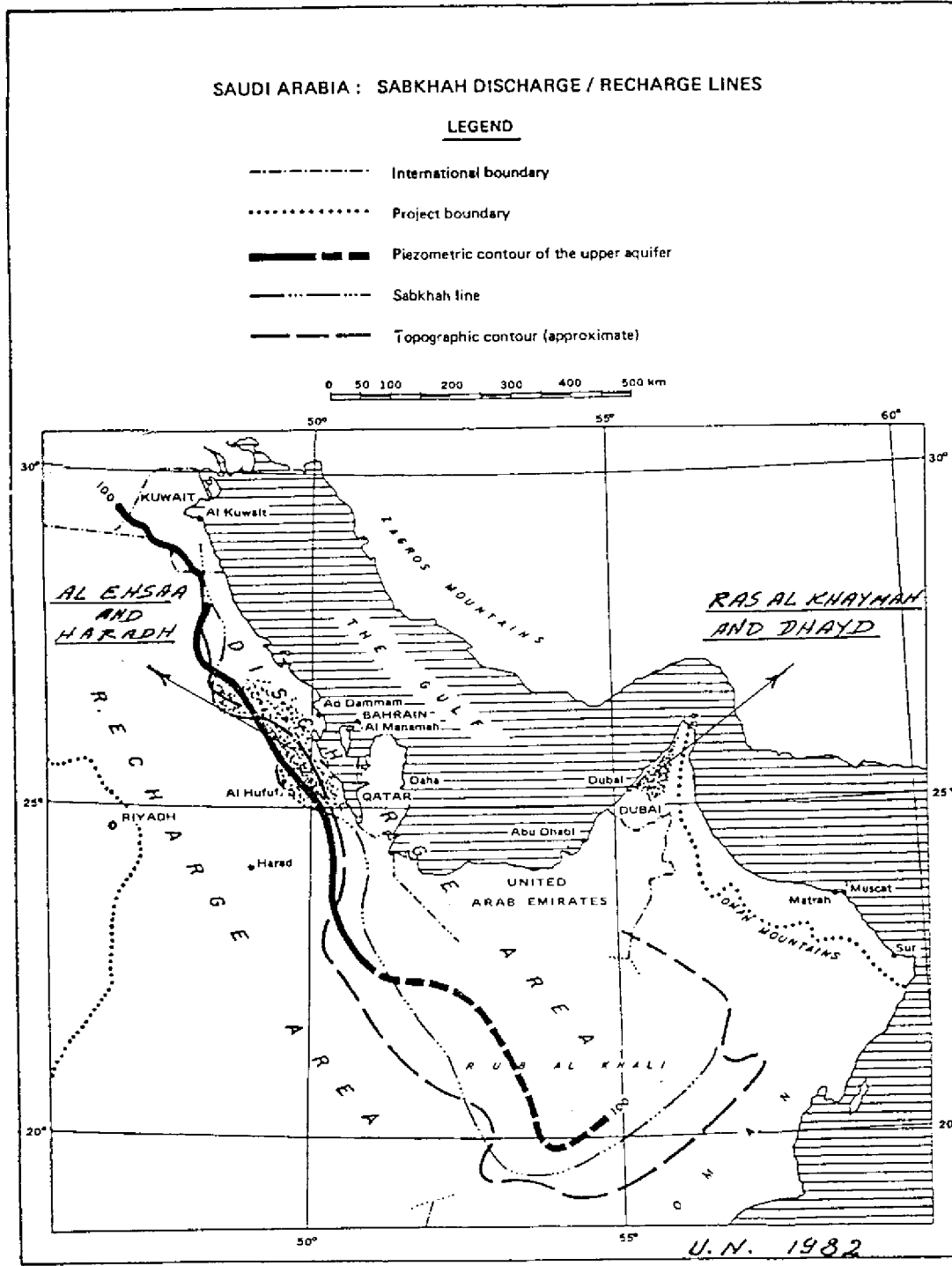
- the Neogene Karstified carbonates (100-200 m thick), having a very wide geographical distribution and acting as the main source of water discharged from the wells and springs ($230 \text{ Mm}^3 \text{ y}^{-1}$) and the water discharged into the sabkhas ($1000 \text{ Mm}^3 \text{ y}^{-1}$). The Neogene aquifer is recharged from the local rainfall on the outcrops as well as from the surface runoff (about $330 \text{ Mm}^3 \text{ y}^{-1}$) or about 20 percent representing the amount

Table 3 Future water-table elevations as calculated by the Groundwater model (m below ground level)

Year	Kharga		Zayat		Dakhla		W. Mawhoob		Abu Muncar		Farafra		Karawein		Bahariya	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
1985	11	9	20	20	1	-15	-15	-20	-51	-51	-66	-74	-29	-29	5	-8
1990	12	10	24	21	1	-5	-6	-16	-46	-45	-52	-69	-26	-26	6	-5
1995	15	13	32	25	3	-1	-3	-12	-41	-41	-38	-65	-33	-33	7	-2
2000	17	18	35	28	8	5	-2	-6	-23	-16	-32	-61	-20	-20	9	-1
2005	20	23	37	31	13	8	7	-3	-10	-22	-20	-54	-5	-5	11	1
2010	23	27	39	33	17	13	12	2	-3	-24	-30	-47	5	5	13	3
2015	25	30	41	35	21	19	17	7	9	-19	-3	-61	20	19	15	5
2020	27	33	43	37	25	21	22	12	17	-14	4	-33	26	25	18	8
2025	29	35	45	39	29	25	26	16	22	-10	10	-27	32	32	21	11
2030	31	37	47	41	32	29	29	19	25	-3	15	-23	38	38	24	14
2035	31	39	48	42	34	32	32	22	27	0	19	-20	43	43	26	17
2040	33	40	49	43	36	34	34	24	30	3	22	-15	47	47	28	20
2045	34	41	50	44	37	36	36	25	32	5	24	-13	50	50	30	23
2085	43	53	63	55	54	52	53	41	50	23	42	4	66	66	50	47

 Artesian conditions
 Pumping uneconomic
 S = Shallow aquifer
 D = Deep aquifer

Figure 19.5 Water Projects in the Gulf and Sabkha Lines



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discharged. The rest (80 percent) comes from storage, from the downward leakage from the Quaternary (in fact of inferior quality) and from the upward leakage from the Eocene (Dammam Formation) and the Eocene-Paleocene (Umm Al Radhuma Formation).

- the Eocene Karstified carbonates (Dammam) having a thickness of over 100 m and also a very wide geographical distribution. This formation is an important source of water for agriculture (annual requirements about 200 Mm³).
- The Dammam Formation is little recharged from rainfall runoff (only about 12 percent of the amount discharged) and the rest comes from the downward leakage (about 200 Mm³y⁻¹) and the upward leakage from the Umm Al Radhuma Formation below (1 400 Mm³y⁻¹ or about 85 percent).
- The Paleocene-Eocene Karstified limestone and dolomite (Umm Al Radhuma), having a thickness of about 200 m and considered as the most important aquifer in the Eastern portion of the Arabian Peninsula. The proven exploitable reserves of water in the Umm Al Radhuma Formation, has been estimated as 16 Gm³ and the total amount discharged annually is about 2 400 Mm³. The annual recharge of this formation from rainfall and runoff is about 400 Mm³ (15 percent only) and the rest is from the upward leakage from the Mesozoic clastic aquifers below. Along the coast the salinity of the water is high (4 000 to 140 000 ppm), but it decreases inland (700 to 3 500 ppm).
- The Mesozoic clastic aquifers, known as Wasia and Biadh Formations, and have a thickness in excess of 500 m (the equivalent of the top Nubian Sandstone in NE Africa). The exploitable reserves of water in these two formations are in the order to 120 Gm³ and the salinity varies from 1 500 to 6 000 ppm, increasing to 170 000 ppm along the coast. The amount of water discharged annually from the clastic aquifers is of the order of 2 100 Mm³, only 5 percent of which is used for municipal purposes and the rest feeds Umm Al Radhuma. The annual recharge from rainfall and runoff is of the order of 400 Mm³ (19 percent).

As outlined above, there is a hydraulic connection among the aquiferous horizons between the Quaternary and the lower Cretaceous. Having this in mind, reviewing the figures given about the upward and downward movement of the water and considering the estimates given by Nori (1983) about the abstraction of water from the Neogene (234 Mm³y⁻¹), the Dammam (500 Mm³y⁻¹) and Umm El Radhuma (130 Mm³y⁻¹), the total amount of water discharged annually from that complex is of the order of 2 000 Mm³. Because this amount is nearly double the amount of water recharged, the deterioration of the quality of water is unavoidable. Reasons for this are:

- the increment of the upward movement of poor quality water from the Mesozoic Clastic aquifers.
- the intensification of salinization processes on the surface and the subsequent downward leakage of saline water from the Quaternary to the Neogene.
- the activation of sea water intrusion into the water bearing horizons.

Leaving the Al Ehsaa-Haradh area and passing eastward to the Ras Al Khayma area in the Northern United Arab Emirates, where intensive agricultural development is underway (+ 23 000 ha) and where there is a serious problem of groundwater depletion (1.0

m to 2.5 my^{-1}). The Ras Al Khaymah area, and its extension southward to Dhayd, is a portion of the bajada on the western side of the Oman Mountains. In that bajada, the Quaternary sands and gravels, which have a maximum reported thickness of about 200 m, act as the main water bearing formation. The water, varying from fresh to brackish, exists at shallow depths from the surface (rarely exceeding 50m). The Quaternary aquifer is little recharged by local rainfall or from the runoff, the annual volume is estimated as 15 to 30 Mm^3 . Because the amount of water released annually from storage in that aquifer is of the order to 160 Mm^3 , the groundwater level in the agricultural areas of the Ras Al Khaymah-Dhyd region is approaching the bottom of the aquifer. This acute situation results in the continuous loss of vegetated patches, due to lack of water and the increase of the salinity of water due to salt water intrusion. (IWACO-BIN HAM, 1986)

The level of groundwater is expected to reach the bottom of the aquifer in less than five years. This means that the cultivated areas of Ras Al Khaymah-Dhayd are endangered, unless a new source of water is found. Fortunately, the recent exploratory work in the Northern portion of the United Arab Emirates led to the discovery of important reserves of good quality water in the Paleozoic-Mesozoic fissured carbonates (estimated 14 Gm^3). Because these new water-bearing layers are within reach of the cultivated areas, a system of water conveyance is at present under consideration to maintain the agricultural production at the 1985 level for a period of about 70-80 years.

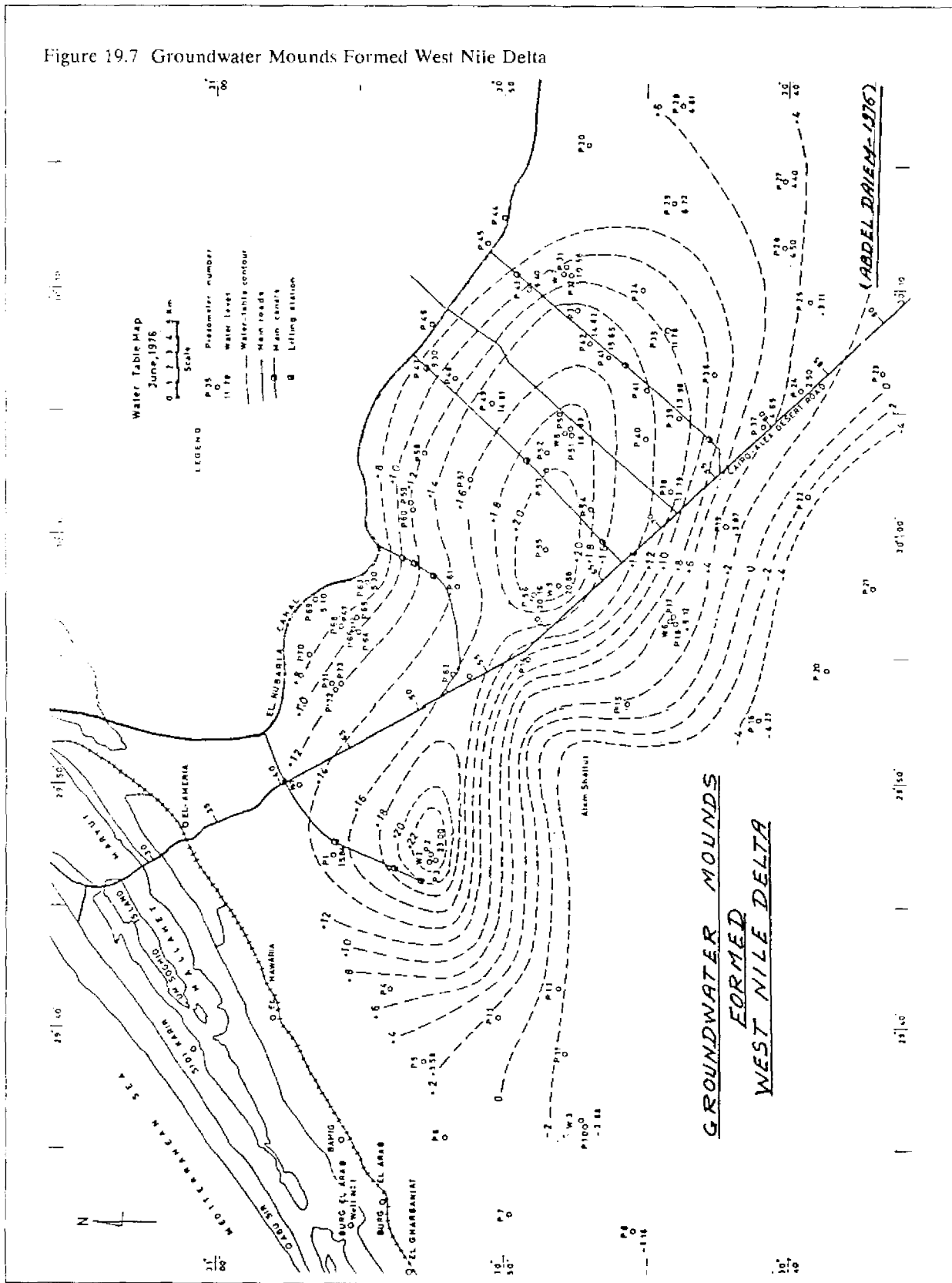
4. Projects West of the Nile Delta

In the New Valley Project area, the groundwater of the Nubian Sandstone Basin is the backbone of the agricultural development plan. In the projects west of the Nile Delta, on the other hand, Nile water is available, particularly since the construction of the High Dam. In such projects the plan was originally to provide new irrigated lands for settlers from the over-populated portions of the Nile Valley. The new lands (about 100 000 ha) occupy portions of the following geomorphic units (Figure 6):

- the old deltaic plains; dominantly underlain by gravels and sand, the surface is occasionally covered by shifting dune sand accumulations. The surface slopes from west to east, in the direction of the Delta Flood Plains (from +40 m to less than +5 m).
- the structural plains; dominantly underlain by calcareous rocks (Late Tertiary), the surface is occasionally covered by calcareous loamy deposits. The structural plains slope from west to east (from +60 m to less than +40 m) and old ill-defined erosional valleys (e.g. Abu Mina) drain these plains to the original delta basin. Within such valleys thick loamy deposits (more than 10 m) are reported and overlie old lagunal deposits.
- the foreshore plains immediately west of the Nile Delta; the surface is topographically developed into a series of elongated calcareous ridges arranged parallel to the coast (elevation varies from +35 m to +10 m, decreasing seaward). These alternate with elongated depressions, the ground elevation of which is close to sea level and which are either filled with thick calcareous loamy deposits or only with wet sabkhas.

Actual land reclamation using Nile water started during the 1960's. The water is obtained from a main canal (El Nubaria Canal), which crosses the area west of the Nile Delta in a NW direction and ends in Mariyut Lake and the Mediterranean to the west of Alexandria. The irrigation water is lifted from the canal by a series of electric pumping stations to open transport canals (from +5.0 m to +50.0 m). Before the irrigation of the new lands, the water-table was present at depths varying from 20 to 60m from the ground

Figure 19.7 Groundwater Mounds Formed West Nile Delta



surface. At present more than 1 000 Mm³ are used each year essentially for irrigation and a high water duty was initially recommended to avoid soil crustation. With the implementation of this water duty and the absence of adequate drainage systems for many years, the groundwater table started rising quickly. This was accelerated by serious seepages of water from the unlined open transport canals as well as from the delivery basins of most of the lifting stations. The picture in June 1976 shows conspicuous groundwater mounds below the new land areas (Figure 7). In such mounds, the depth of the groundwater table is no more than 2 m below the ground surface and in some cases it reaches the surface and forms dry and wet salt marshes. With the progressive rise of the water table the saline groundwater started moving into the irrigation canals, including the El Nubaria itself, and also into the suction basins of most of the lifting stations. This situation has endangered the agricultural production not only in the elevated new lands, but also in the old lowlands of the Delta.

In the mid-1970's, plans for the construction of an efficient drainage system were established. The main drain, having its outfall in the Mediterranean far to the west of Alexandria, was only completed in the mid-1980's. The ultimate discharge capacity of the drain is of the order to 2 000 Mm³y⁻¹ and the present discharge capacity is only 25 percent less than that amount. It is expected that after the completion of the secondary drains, at present under way, the full capacity of the main drain will be maintained. This together with the gradual shift from the basin irrigation system, will allow for the gradual lowering of the groundwater table and consequently to upgrading of the agricultural production of an area exceeding 100 000 ha.

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PAPER 20

INCIDENCE DES AMENAGEMENTS DE LA VALLEE DU FLEUVE SENEGAL SUR LE LAC DE GUIERS ET PROPOSITIONS DE GESTION FUTURE DE L'ECOSYSTEME LACUSTRE

*F-X. Cogels*²³

Introduction

Situé en rive gauche du fleuve Sénégal, dans la zone du Delta fluvial (fig. 1), le lac de Guiers occupe une dépression longue de 50 km et large de 7 km au maximum. Ce lac "plat" sahélien (profondeur moyenne : 2 m) constitue la principale réserve d'eau douce de surface du pays. Divers aménagements successifs ont permis d'en faire un véritable réservoir: endiguement des rives de la région nord et nord-ouest, barrage à son extrémité sud. Les utilisations de l'eau directes ou indirectes sont multiples :

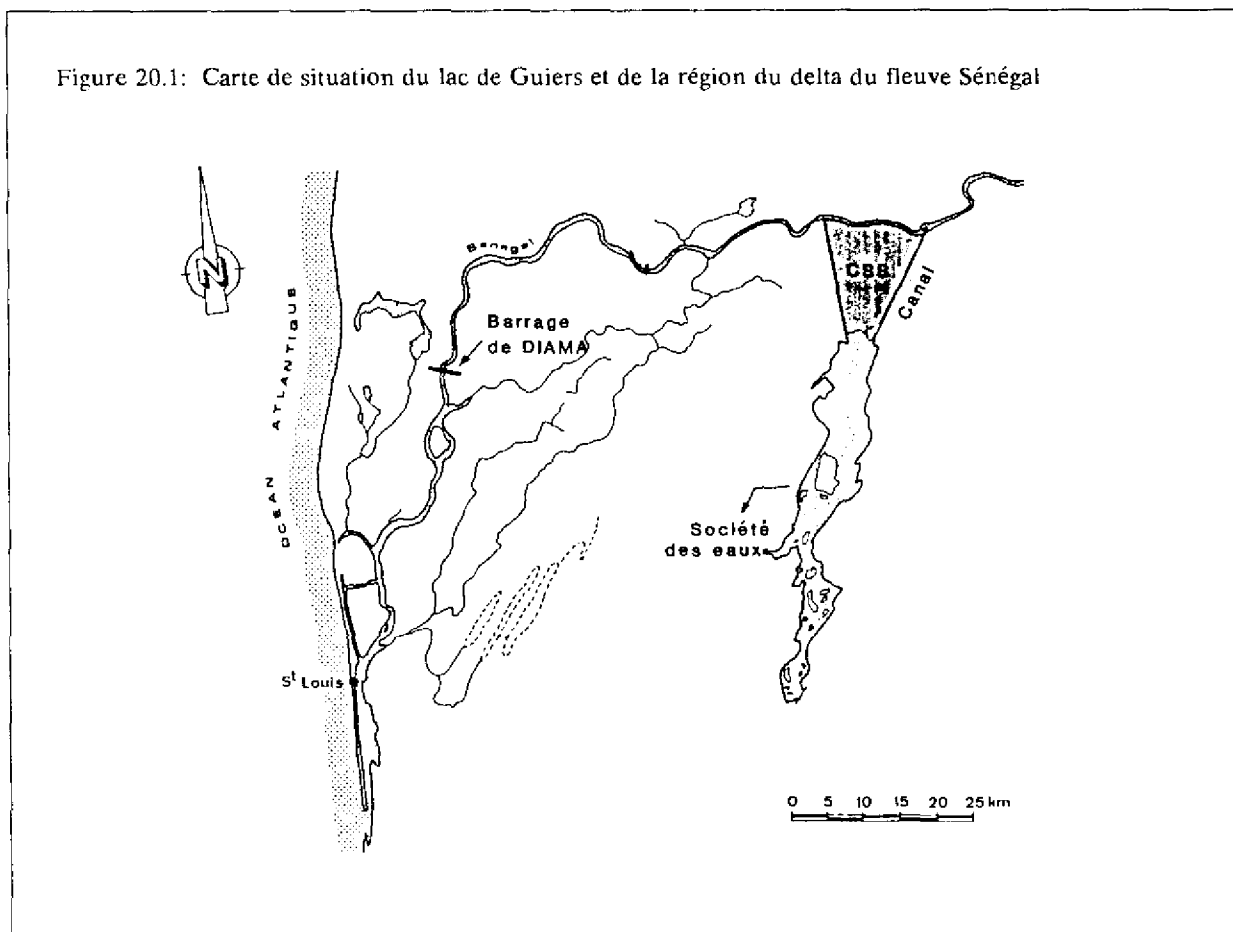
- *cultures irriguées*: 6 000 ha de canne à sucre exploités par la Compagnie Sucrière Sénégalaise (CSS) dans la zone nord du lac. L'eau d'irrigation est prélevée dans le Guiers;
- *production d'eau potable*: la Société Nationale des Eaux pompe et traite quotidiennement plus de 50 000 m³ d'eau destinée essentiellement à la ville de Dakar;
- *cultures traditionnelles de décrue*: pratiquées tout autour du lac au fur et à mesure du retrait des eaux en cours d'année hydrologique. Ces dernières années, ces cultures ont suppléé au déficit de production des cultures pluviales par suite des conditions climatiques défavorables;
- *la pêche traditionnelle*: fournit annuellement quelque 1 600 tonnes de poisson et compense (partiellement) la forte diminution des prises constatée dans le fleuve Sénégal;
- d'autres activités tirent profit du plan d'eau: *l'élevage, les cultures maraîchères* et les petits *périmètres irrigués* (riziculture).

Fonctionnement Ancien et Futur du Système Fluvio-Lacustre

- (a) *Jusqu'en 1985* l'existence du lac dépendait uniquement de la crue du fleuve Sénégal, de son importance et de sa durée, l'alimentation du plan d'eau se faisant par l'intermédiaire d'un canal de 17 km reliant le milieu fluvial au milieu lacustre. L'année hydrologique du lac se divisait ainsi en 2 phases :

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Figure 20.1: Carte de situation du lac de Guiers et de la région du delta du fleuve Sénégal



1. phase de remplissage correspondant à la crue fluviale soit en moyenne d'août à septembre;
 2. Phase d'isolement débutant à l'amorce de la décrue fluviale. Un système de barrages situés à l'embouchure du canal dans le fleuve permet de couper la relation fluvio-lacustre en temps voulu, afin d'éviter l'écoulement du plan d'eau vers le fleuve. Durant cette phase de 9 mois (en moyenne) le niveau du lac évoluait sous la dépendance des divers prélèvements et de l'évaporation, les apports pluviaux étant négligeables. Les variations de niveau des eaux entre début et fin de phase étaient importantes, de l'ordre de 2,5 m.
- (b) A partir de 1985 le régime hydrologique du fleuve et du lac est et sera encore profondément modifié par la mise en fonction de deux barrages, l'un situé à Diama à 30 km de l'embouchure du fleuve dans l'océan (fig. 1) et dont la fonction première est d'empêcher la remontée d'eau de mer dans le fleuve en étiage. Ce barrage est fonctionnel depuis 1985. L'autre barrage situé à Manantali (Mali) aura une fonction régulatrice des débits fluviaux et devra permettre la mise en valeur de près de 300 000 ha de cultures irriguées dans la vallée; cet ouvrage est en construction.

Le régime hydrologique du lac sera modifié par la mise en oeuvre des deux barrages :

- le barrage de Diama crée à son amont un réservoir d'eau destiné à l'irrigation et qui s'étend bien au-delà de la confluence fleuve-lac
- le barrage de Manantali devra régulariser les débits fluviaux à $150 \text{ m}^3\text{s}^{-1}$ à hauteur de la jonction fluvio-lacustre.

Ces aménagements hydrauliques permettront donc de disposer à longueur d'année d'eau en suffisance pour alimenter le lac à volonté; ce dernier ne sera donc plus soumis aux aléas de la crue fluviale mais pourra être hydrauliquement géré comme un véritable réservoir.

Passons alors en revue les incidences potentielles de ces aménagements sur l'environnement du lac de Guiers.

Incidence des Aménagements Hydrauliques de la Vallée du Fleuve Sénégal sur le Milieu Lacustre et Bases de la Future Politique de Gestion

Nous ne traiterons ici que les incidences liées directement ou indirectement à la gestion quantitative future des eaux du lac. Les aspects qualitatifs ont été traités précédemment. (Cogels, 1984, GAC et al, 1986).

(a) *Les cultures de décrue*

Puisque leur existence dépend entièrement du retrait annuel des eaux du lac, le maintien du plan d'eau à un niveau constant, comme cela pourrait se faire, les condamne irrémédiablement. Or, leur apport tant strictement protéique que financier (US \$ 1 000 $\text{ha}^{-1}\text{an}^{-1}$) est essentiel aux habitants de cette région. Les cultures irriguées futures de la vallée du fleuve ne pourront fournir une production aussi diversifiée que celle obtenue en culture de décrue (tomates, manioc, courges, melons, patates douces ...). Le maintien d'une *variation annuelle de niveau des eaux* du lac, naturelle ou semi-artificielle, est donc indispensable.

(b) *Les cultures irriguées*

Leur existence est indépendante de la hauteur des eaux lacustres si le lac se maintient à un niveau supérieur au seuil de pompage. Ce seuil est connu avec précision. Le *non-dépassement d'une cote-limite* en fin de phase d'isolement est donc le critère fondamental de gestion.

(c) *La production d'eau potable*

Elle dépend d'une part du non-dépassement du seuil de pompage dans le lac et d'autre part de la qualité des eaux prélevées. Or leur degré de minéralisation augmente tandis que diminue le volume lacustre en cours de phase d'isolement, principalement sous l'effet de l'évaporation. Puisqu'une charge minérale dissoute excessive entraîne un surcoût du traitement des eaux, le *maintien du lac à un niveau suffisant* en fin de phase d'isolement est ici un critère doublement valable.

- (d) *Les potentialités piscicoles* lacustres sont assujetties d'une part à l'importance de la reproduction du poisson, d'autre part à une gestion des stocks correcte. La reproduction s'effectue en saison chaude et correspond à la période de remplissage du lac. Le stock piscicole dépend aussi de l'intensité et de la qualité de l'effort de pêche. Or ces dernières années, les niveaux extrêmes atteints en fin de phase d'isolement, par suite de mauvais remplissage 9 mois plus tôt, ont directement et indirectement porté atteinte au poisson: conditions d'existence précaires et réduites à quelques grandes mares surchauffées et surtout effort de pêche surintensif sur le stock piscicole particulièrement vulnérable. *Bon remplissage du lac* et *non-dépassement d'une cote-limite inférieure* sont ainsi les deux éléments-clés de l'existence d'une faune ichtyologique abondante et équilibrée.
- (e) Au cours de ces dernières années, les importantes variations annuelles du niveau des eaux ont permis de limiter le développement de la végétation aquatique supérieure (typhaies). Maintenir le lac à un niveau plus constant en cours d'année entraînerait très probablement le sur-développement végétal et indirectement favoriserait l'apparition de maladies comme le paludisme et surtout la bilharziose, absente du lac actuellement. De plus la végétation aquatique (comme le typhaies) peut être un excellent refuge pour les oiseaux dévastateurs des cultures (*Quelea quelea*). La *variation annuelle de niveau des eaux* est donc le facteur limitant principal de l'extension végétale..

Mentionnons enfin le grand projet de construction d'un canal reliant le sud du lac de Guiers à la ville de Dakar, assurant ainsi l'approvisionnement en eau douce des agglomérations et villes le long de son parcours et le développement de la petite agriculture. Ce projet dont les contraintes hydrauliques ne sont pas encore définitivement fixées aura également de profondes répercussions sur le milieu lacustre; elles restent cependant encore à préciser.

Deux grands principes de gestion quantitative des eaux du lac devront donc être suivis:

- *Retrait progressif* des eaux en cours de phase d'isolement entre octobre et juillet.
- *Non-dépassement d'un niveau limite inférieur* en fin de phase d'isolement.

Il faudra donc pouvoir:

- *Calculer* avec précision et compte tenu des besoins à prévoir (pompages et prélèvement divers) la cote exacte à atteindre dans le lac en fin de remplissage, afin d'assurer un retrait progressif des eaux tout en ne dépassant pas la cote limite critique à déterminer.
- *Prédire* au jour le jour l'évolution de la cote du lac; ceci doit permettre d'éventuels réajustements de niveau par ouverture des barrages à l'embouchure fleuve-lac en cours de phase d'isolement. Rappelons que l'eau est disponible en permanence dans la retenue de Diama.

Enfin, la réduction maximale des pertes en eau par évaporation étant aussi l'un des buts recherchés en région sahélienne, il convient de gérer le lac en maintenant sa surface en permanence la plus faible possible.

Tout ceci ne peut se réaliser qu'avec l'aide de l'ordinateur pour lequel nous avons étudié un modèle mathématique de gestion quantitative des eaux du Guiers.

Modèle de Gestion

(a) Les éléments du modèle de gestion

Les éléments de base sont:

- Le calcul précis de la surface et du volume du lac en fonction du niveau des eaux. Ceci a été étudié précédemment. (Cogels, 1984);
- les paramètres hydrologiques directement quantifiables : prélèvements (pompages, irrigation) apports (pluviaux, rejets...);
- Le taux d'évaporation du lac et son évolution annuelle. Ce dernier point a été étudié sur la base du bilan hydrologique lacustre dont le schéma général est repris ci-après. (Figure 2). On y remarque que l'évaporation représente quelques 80 pourcent des pertes en eau du lac (Cogels et al. 1981). Connaissant les volumes évaporés mensuellement et les surfaces du Guiers correspondant aux mêmes périodes nous pouvons alors calculer les hauteurs d'eau évaporée. L'évaporation totale annuelle du lac est de 2,20 m soit très semblable à celle enregistrée dans d'autres lacs sahéliens, Tchad (2,34 m) (Pouyaud, 1979) et Bam au Burkina Faso (2,15 m) (Roche, 1980; Riou, 1975).

Connaissant l'évaporation moyenne mensuelle (moyenne entre 1976 et 1982) et son évolution de mois en mois, on peut alors tenter d'extrapoler son évolution "type" intra-mensuelle et par là son estimation (graphique) *quotidienne* (Figure 3).

L'addition des hauteurs d'eau quotidiennes évaporée, estimées par méthode graphique, reste dans ce cas en parfait accord avec la hauteur d'eau totale mensuelle calculée par le biais du bilan hydrologique. Sur l'ensemble des 72 mois considérés (1976 à 1982) le coefficient de corrélation entre ces deux valeurs est en effet de 0,998.

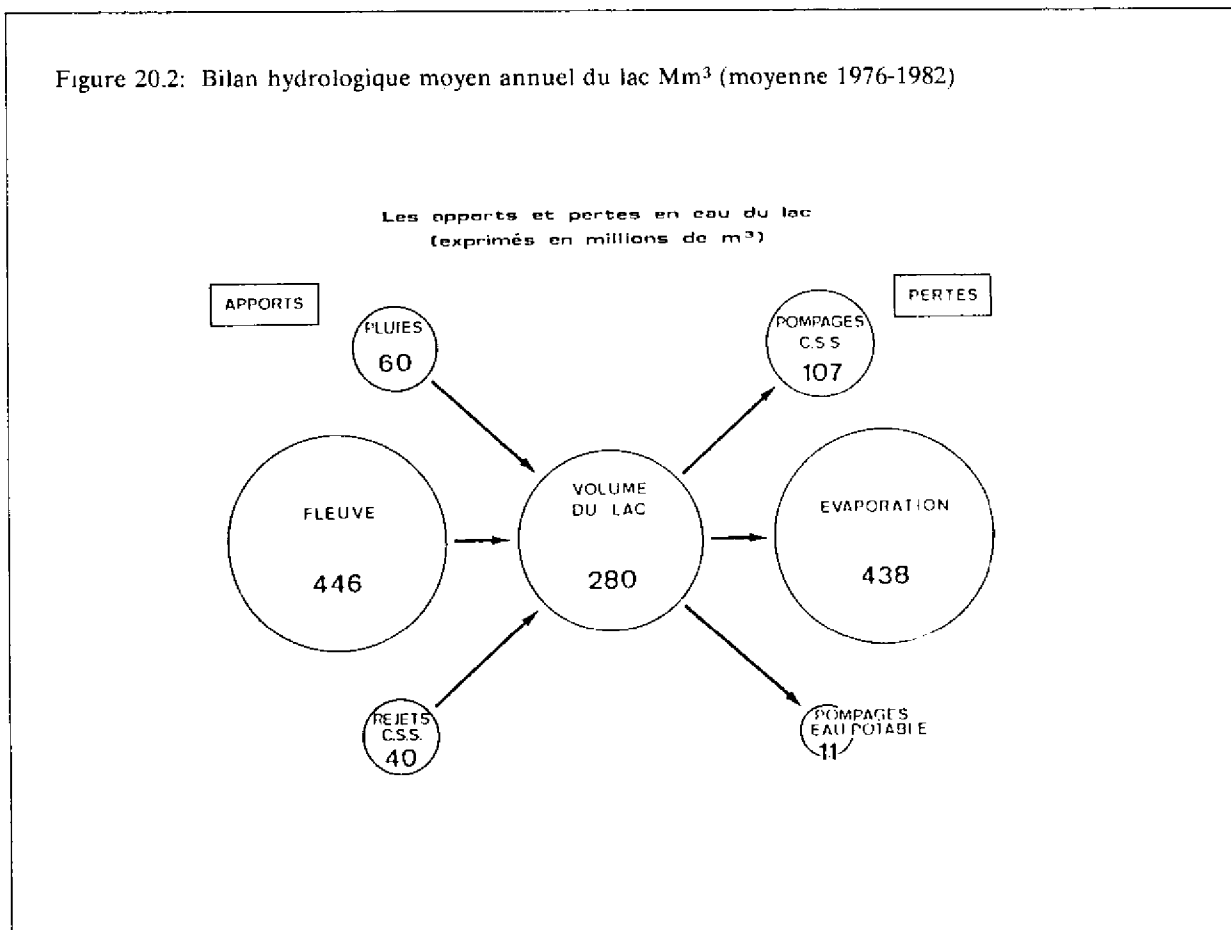
Modèle mathématique

La formule mathématique ci-dessous intègre les éléments qui permettent de calculer la cote du lac à attendre au jour n connaissant celle à ne pas dépasser (cote limite inférieure) x jours plus tard, et ce compte tenu des prélèvements, rejets et apports divers pouvant intervenir dans le bilan hydrologique durant cet intervalle de temps. En d'autres termes : Quelle sera la cote à atteindre dans le lac le 1er octobre, en fin de phase de remplissage, de manière à ne pas dépasser au 31 juillet de l'année suivante (fin de phase d'isolement) la cote limite inférieure déterminée?

$$H_n = H_{n+1} + \Delta H(V_{pn}) + \Delta H(V_{en}) - \Delta H(V_{an}) - \Delta H(V_{pon})$$

où

- H_n = cote du lac au jour n
- H_{n+1} = cote du lac au jour n + 1
- $\Delta H(V_{pn})$ = hauteur d'eau correspondant aux pompages du jour n
- $\Delta H(V_{en})$ = hauteur d'eau correspondant à l'évaporation du jour n
- $\Delta H(V_{an})$ = hauteur d'eau correspondant aux apports (éventuels) au jour n
- $\Delta H(V_{pon})$ = hauteur d'eau correspondant à la pluviométrie du jour n

Figure 20.2: Bilan hydrologique moyen annuel du lac Mm³ (moyenne 1976-1982)

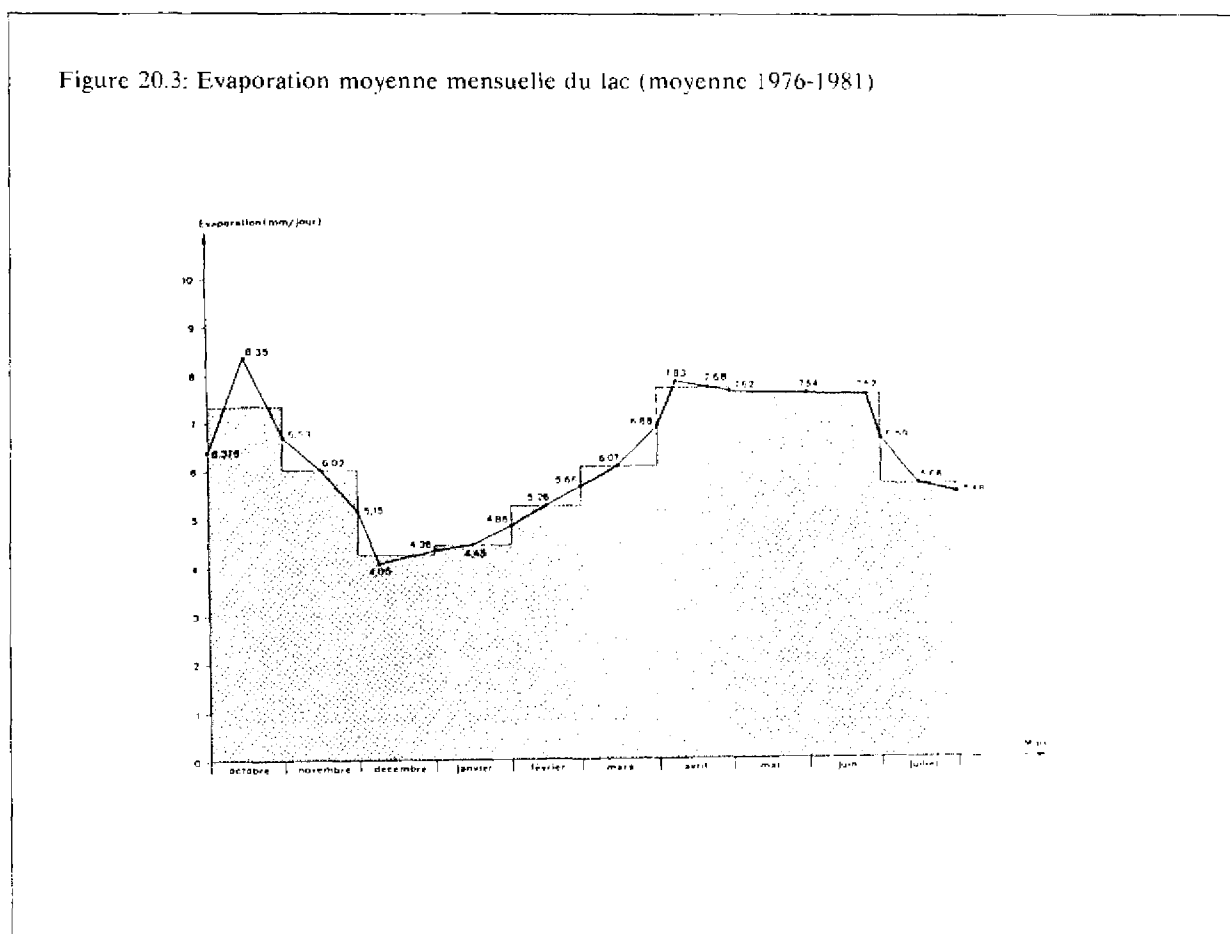
La transformation de volumes apportés ou prélevés en une différence de hauteur d'eau s'effectue par simple division de ces mêmes volumes par la surface du lac au jour n . La pluviométrie ne peut évidemment être prise en compte dans le cas d'un modèle prévisionnel de l'évolution future de la cote du plan d'eau. L'intervention du paramètre dans le modèle permet cependant le réajustement des calculs en cours d'année en fonction des éventuelles précipitations.

Résultats

Ecrit en langage "Basic", le modèle mathématique a été testé sur 6 années hydrologiques pour lesquelles nous disposons de toutes les données quantitatives nécessaires y compris les apports pluviométriques, soit les années 1976 à 1982. Durant cette période, le niveau atteint en fin de remplissage du lac dépendait uniquement de l'importance et de la durée de la crue fluviale. C'est pourquoi le modèle a été testé "à l'envers" en calculant la cote atteinte en fin de phase d'isolement sur base de sa cote en début de cette même phase et des divers paramètres hydrologiques.

Le tableau 1 indique les résultats obtenus, qui permettent de tester la fiabilité de ce modèle. Deux cas sont envisagés selon la prise en considération ou non des apports pluviométriques.

Figure 20.3: Evaporation moyenne mensuelle du lac (moyenne 1976-1981)



La différence enregistrée entre résultats observés et calculés selon le modèle est de l'ordre de 3 pourcent si l'on tient compte des apports pluviométriques et de 3.8 pourcent dans l'autre cas. La fiabilité du modèle utilisé est donc satisfaisante et permet de conclure à une très bonne répétitivité annuelle de l'évaporation quotidienne du plan d'eau puisque l'erreur maximale enregistrée n'est que de 6.51 pourcent (année 1979-1980). D'autre part on remarque que la pluviométrie intervient très peu dans le bilan général. L'erreur induite par la prise en compte de ce paramètre est de l'ordre d'un pourcent.

La figure 4 schématise l'évolution du niveau du lac, observé et calculé d'après le modèle au cours de 2 années hydrologiques et sans prise en compte des apports pluviométriques. On remarque la très bonne correspondance entre les deux courbes qui sont presque superposées.

Tel que programmé actuellement, le modèle permet de suivre avec précision l'évolution du niveau du lac en fournissant la cote prévisionnelle de 10 en 10 jours. Ceci devrait permettre d'éventuels réajustements de niveaux par des apports supplémentaires en cours d'année.

Année hydrologique	Cote observée	CAS 1		CAS 2	
		Cote calculée	% erreur	Cote calculée	% erreur
1976-77	-1.04	-1.17	6.02	-1.19	6.94
1977-78	-1.14	-1.09	2.13	-1.19	2.13
1978-79	-0.50	-0.52	0.94	-0.61	5.19
1979-80	-1.10	-0.96	6.51	-0.99	5.12
1980-81	-0.65	0.61	1.78	-0.63	0.89
1981-82	-0.57	-0.56	0.43	-0.63	2.58
Moyenne			2.97		3.81

Tableau 1: Comparaison des niveaux lacustres (en fin de phase d'isolement observés puis calculés selon le modèle mathématique (m.IGN) et pourcentage d'erreur entre les deux valeurs

cas 1 : avec prise en compte des apports pluviométriques

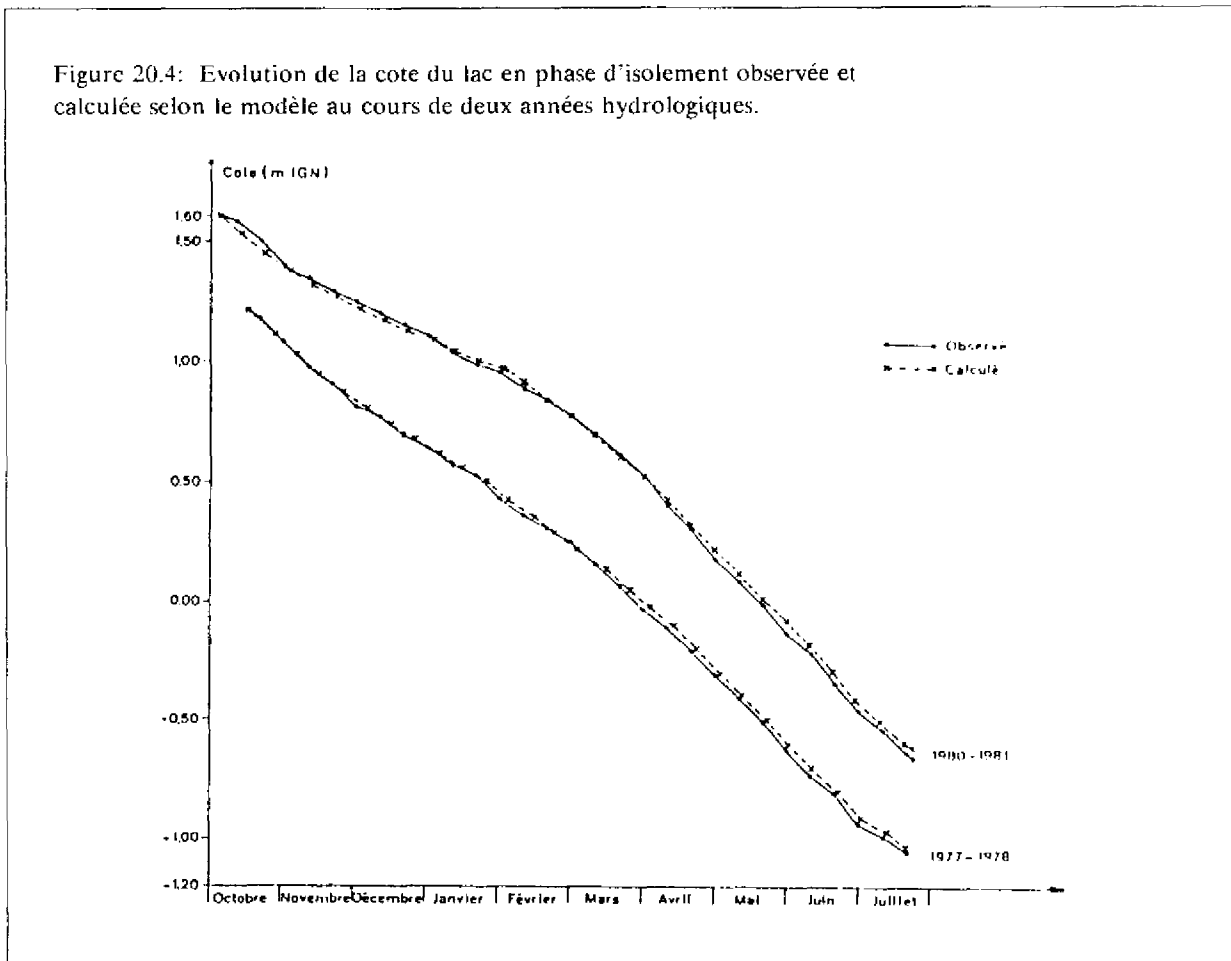
cas 2 : sans prise en compte des apports pluviométriques

La figure 5 illustre enfin l'utilisation pratique du modèle en indiquant la cote à atteindre en fin de phase de remplissage, et l'évolution du niveau du lac compte tenu de diverses alternatives de volumes d'eau prélevée et ce tout en ne dépassant jamais la cote limite inférieure en fin de phase d'isolement. A titre indicatif et sans nous étendre ici sur sa justification, cette cote limite a été fixée au niveau -0.50 m.

Conclusions

L'outil mathématique de gestion des eaux du lac de Guiers tel que nous l'avons proposé résulte de plusieurs années de mesures et d'observations hydrologiques. Sa fiabilité semble prouvée. Son grand avantage est de pouvoir simuler rapidement toutes les situations hydrologiques du lac compte tenu des différents paramètres entrant en jeu, tant au niveau des apports qu'à celui des pertes. Les aménagements prévus et en cours dans la vallée du Sénégal auront en tout cas des effets bénéfiques sur l'hydrologie du lac puisque son remplissage ne posera plus aucun problème. La politique de gestion future des eaux ne pourra cependant avoir pour seul critère l'aspect hydrologique. L'approche de la

Figure 20.4: Evolution de la cote du lac en phase d'isolement observée et calculée selon le modèle au cours de deux années hydrologiques.

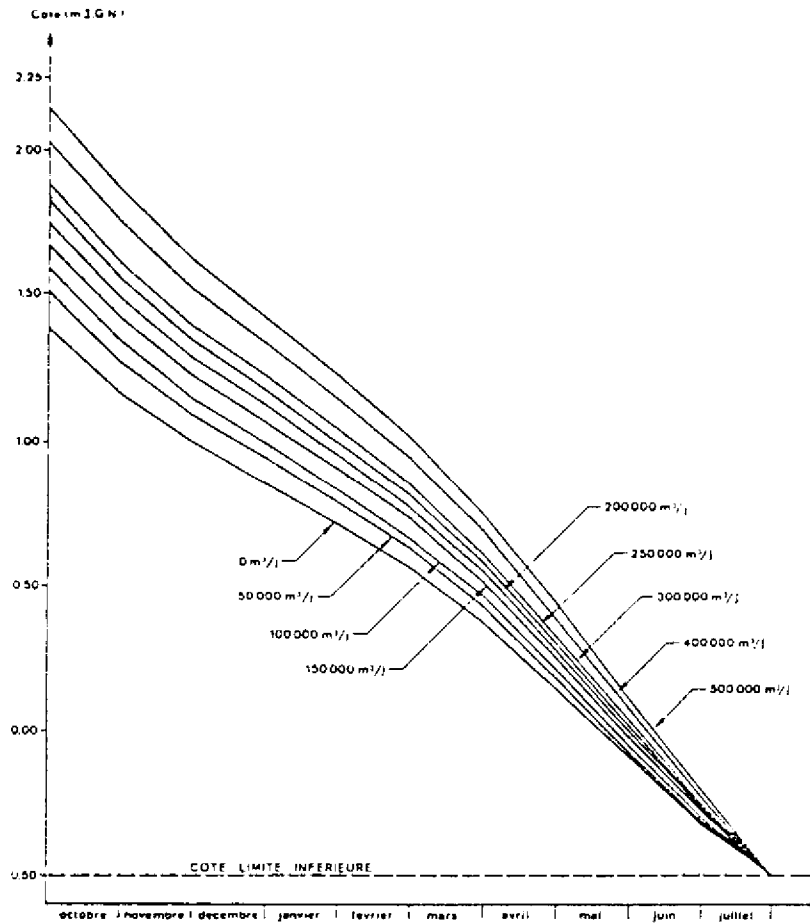


problématique doit être globale et inclure les paramètres écologiques, économiques et humains. Dans le cas du lac de Guiers, il est possible d'assurer le contentement et les intérêts des divers utilisateurs des eaux. Il reste à en avoir la volonté et aussi les moyens!

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Figure 20.5: Evolution de la cote du lac en phase d'isolement en fonction de diverses alternatives de prélèvements d'eau.



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PAPER 21

ENVIRONMENTAL IMPACTS OF WATER RESOURCES PROJECTS: THE INDIAN EXPERIENCE

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1. Introduction

The progress of civilisation is intimately connected with the advances in water resources development. Water is a very precious gift of nature to all living beings, particularly to mankind. Variations in availability of water in time, quantity and quality cause significant fluctuations in the progress of a country. Hence, there exists the need for conservation, proper exploitation and management of this precious resource for the betterment of the economic status of the country. At a time when harnessing of all available water resources for the development of the country has assumed utmost urgency, it is essential to adopt the latest technologies and methods, for deriving lasting benefits. Water forms a large part of the environment and influences, to a great extent, the other parts of the environment also. It is essential to life and thus the manner and extent of development, control, exploitation and utilisation of this resource can result in an improvement in the total environment or can lead to its degradation to a great extent. Development should not only encompass economic and socio-political aspects but should also accord equal importance to the management of the environment.

2. Environmental Aspects of Water Resources Development

The environment is a complex system consisting of physical, biological and social resources. Water resources development can have both beneficial and adverse impacts on the environment. The beneficial aspects are directly related to the objectives of the multi-purpose projects like hydro-power generation, irrigation, flood control, domestic and industrial water supply, etc., and indirectly related to growth of ancillary agro-industries and other industries using the available additional power. Some of the adverse impacts due to implementation of water resources projects are submergence of human habitations, crop lands, mineral deposits, changes in the downstream river regime etc. The adverse impacts, however, are not insurmountable and remedial measures to mitigate them are available. The strategy of development would be to strive for the maximum benefits with minimum adverse effects.

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3. Beneficial Aspects of Water Resources Development, Related Adverse Impacts and Mitigating Measures

Water resources projects undoubtedly usher in some measure of economic prosperity. Whether this benefit can be achieved with acceptable levels of adverse impacts needs careful evaluation at the planning stage.

3.1 Irrigation

Water is the prime point for agricultural production. Due to construction of reservoirs there is an assured water supply for a substantial increase in irrigated land under different crops. The cropping pattern can also be modified beneficially with more coverage by cash crops or food crops. As a result of the construction of major medium and minor irrigation schemes since Independence, about 68 Mha of land was estimated to have been brought under irrigation in the country up to 1985²⁴. To cite a few examples of individual projects in India, about 0.87 Mha of land was brought under irrigation by construction of Nagarjuna Sagar dam across the river Krishna in Andhra Pradesh and 0.22 Mha of land was brought under irrigation by the construction of Hirakud dam²⁵ across Mahanadi River in Orissa.

However, in some parts of the country excessive application of water without adequate drainage in the command area has resulted in adverse impacts such as waterlogging and salinity. For instance, command areas of 27 000 ha and 30 000 ha are waterlogged under the left and right bank canals of Nagarjuna Sagar reservoir. Seepage from unlined canals in the irrigation systems aggravates the problem. To counteract this menace, drainage master plans are being prepared and implemented. Canals are being lined and other water conservation management methods are being introduced. In some projects like Uka-Kakrapar Project (Gujarat) where waterlogging has occurred in some places, measures like eucalyptus planting, conjunctive use of surface and groundwater, etc. have been adopted. In Ramganga Project (Uttar Pradesh) this impact is being offset by proper planning and the construction of drains.

The return flows from irrigated areas usually drain into the river. This return flow has a high concentration of fertilisers and pesticides which are washed away from the irrigated fields by the excess irrigation water draining through the fields. For instance, the River Ganga is affected by pollution near Garhmukteshwar due to washouts of pesticides on fields, bleaching industries, pollution by seepage from industrial waste ponds, sugarcane crushing, etc. Proper on-farm water management and cultivation practices are being introduced in many areas to avoid wasteful irrigation. This measure diminishes the volume of return flow and consequently the pollution from fertilisers, etc.

3.2 Hydropower generation

The cost of hydropower generation is very low and the water resource for hydropower is renewable, which a developing country like India can ill-afford to ignore for its industrial and other developmental activities. Hydropower generation has increased from 559 MW during the pre-plan period to 15 812 MW up to March, 1985²⁶. This increase in hydropower

²⁴ Write (CWC 1981).

²⁵ 6th 5-Year Plan.

²⁶ 6th 5-Year Plan.

generation has tremendously helped the country's industrial growth and consequent rise in per capita income. There are no known significant adverse impacts on account of release of water through turbines after power generation. The adverse effects of the creation of reservoirs are the same as those of multipurpose or irrigation reservoirs.

3.3 Ancillary industries

Water resources development projects bring in their wake the development of ancillary industries such as sugarcane crushing plants, cotton ginning etc. Such industries create additional employment potential.

However, the growth of industries can create pollution problems in the rivers as the effluents are usually directly returned to the river either untreated or partially treated. This makes the water unfit for drinking and other purposes in the downstream reaches. Treatment of effluents must be undertaken to bring down the level of pollution.

3.4 Flood control

Many reservoirs are built for the multiple purposes of irrigation, power generation and flood control, thus saving loss of life and property in addition to providing the benefits mentioned above. Due to construction of Hirakud reservoir, floods are moderated in the Mahanadi delta. The Damodar Valley dams have reduced the flood losses in the Lower Damodar region. Due to Ukai dam (Gujarat), Surat and other downstream areas are free from large floods. As against the flood peak of 42 480 m³s⁻¹ in 1968, the maximum flood released since the completion of the dam has been 13 620 m³s⁻¹ in 1973. Though the fear of floods downstream has almost disappeared in the Ukai-Kakrapar project area, the flood control measures were not accompanied by proper flood plain regulation. As a result habitations have grown in the river bed itself and seasonal cultivation is also practised. This has not only put a restriction on the safe discharge to be released from the spillway but has also created problems of water pollution, developments of slums, etc. (Govt. Gujarat).

To reduce flood damage and loss of life, efficient flood forecasting networks on all major river systems in India have been set up by the Central Water Commission to forewarn people for a timely evacuation of the flood plain and advance action for strengthening the levees, gearing up of flood fighting arrangements, etc. The network has about 147 forecasting stations spread throughout the country. The integration of forecasting with the operation and regulation measures at reservoirs has become an added asset for flood regulation. Legislation to curb unplanned and indiscriminate development of the flood plains is also under consideration.

3.5 Health

Since the creation of reservoirs there is a perennial source of adequate water supply. Due to the availability and supply of water in the command areas as well as in nearby cities, there has been a marked improvement in the general health of the people. Further, the level of nutrition, as a result of increased food production, has also improved. Socio-economic surveys conducted for Rajasthan Canal Project (Council of Applied Research, 1983) and Mahi- Kadana Project (Gujarat) reveal a general improvement in the health of the people.

However, storage reservoirs generally cover large areas with shallow weed-infested shore lines providing breeding grounds for disease carrying mosquitoes. Malaria occurs commonly

among construction labourers and other populations. For instance, the Raichur district of Karnataka State has become highly endemic for malaria after Tungabhadra dam and canal network were built. Fortunately, schistosomiasis which is associated with irrigation development in most African countries has not been a problem in India.

In order to mitigate the above adverse impacts the following measures are being adopted are as follows:

- (a) periodical health check up and provision of medicines.
- (b) anti-malarial measures such as spraying of DDT to reduce mosquito population.
- (c) lining of canals to reduce seepage of water through canals in command areas and prevent waterlogging and consequent breeding grounds for mosquitos (Govt. of Gujarat).
- (d) nursing predatory fish species in the reservoirs and systematic drainage of stagnant pools to inhibit mosquito breeding.

It may be mentioned that reservoir water level fluctuations to inhibit mosquito breeding is not feasible due to the short monsoon season when the reservoir is filled and continuous depletion during the rest of the year with little or no rainfall.

3.6 Aquatic life

The creation of a large lacustrine environment helps to increase fish production. Many new species have taken firm hold in the newly created environment. The most notable examples are the establishment of fast growing Gangetic carp in the reservoirs of Krishna and Cauvery in the peninsula of India and Gobind Sagar, in the north-west Himalayan region. Reservoir fishery has also been a success in Mahi-Kadana (Gujarat) and Ukai reservoirs. The Ukai dam project can be cited as an instance for suggesting certain definite steps for improving fish production where no commercial species existed in the river before impoundment. The reservoir was stocked with 76 million major carp fingerlings during 1972-81. Breeds from other rivers were transplanted during 1972-75. In the 1975 monsoon, there was large-scale breeding and commercial exploitation started through the co-operative societies. Eleven such societies benefitting 10 000 displaced families are now fishing in the reservoir with an annual catch of 4 000 t valued at 20 million rupees. At Ukai, two fish farms with breeding, hatching and spawnery units under artificially-controlled climatic and physio-chemical conditions have been established with encouraging results. Breeding of hilsa by stripping and rearing of the young ones has been successful. Several training programmes in fish cultures are also periodically arranged. Such developments in fisheries are being implemented in other project areas also. The fisheries of Jayakwadi project (Maharashtra) and Tungabhadra project (Karnataka) are good examples.

However, any artificial physical obstructions such as dams, weirs and barrages which prevent the free passage of migratory fish to feeding or spawning grounds is bound to reduce or even to prevent the propagation and perpetuation of stocks, leading to a decline of the fisheries. The flora and fauna, which cover the bed, condition the life and growth of fish. As a result of the dam across the River Beas at Pandoh, winter catches of brown trout downstream at Mandi and regular winter fishery of snow trout down the River Beas to Naduan are on the decline.

The above ill-effects can be mitigated to a certain extent by providing fish ladders in the hydraulic structures as at Farakka barrage (West Bengal) and artificial fish hatcheries downstream of reservoirs by creating fish barriers, etc. Harmful aquatic weeds must also be cleared periodically.

3.7 Tourism

Gardens have been developed around many dam-sites in the country like Ukai, Ravishankar (Madhya Pradesh), K.R.S. Dam (Karnataka), Sathanur (Tamil Nadu), Malampuzha (Kerala), Jayakwadi (Maharashtra) enhancing the beauty of the surroundings. The additional flora have contributed to improving the environment. These gardens have become important tourist spots in the country and to indicate the significance of these lovely recreation centres, the Saint Dnyaneshwar garden constructed as a part of Jayakwadi Project (Maharashtra) can be cited. The garden extends over 124 ha of land on the left flank with developments on the lines of the famous gardens at Brindavan in Karnataka, Pinjore in Haryana and Shalimar in Kashmir. The garden has 330 species of trees to attract the tourists. The garden is like an attractive hill station and has beautiful flowerbeds, expansive lawns, exquisite fountains, springs in water channels with decorative lighting. The garden has also orchards with fountains as an added attraction.

The large reservoir can be used for boating by the people visiting the gardens. For example, while boating in the Thekkadi Lake of Periyar dam (Tamil Nadu), people can see wild life such as elephant and bison in the forest around the reservoir. The additional revenue from tourism is helpful in augmenting resources for other developmental activities. There are no significant adverse impacts stemming from this aspect of water resources development projects.

4. Loss of Resources

The loss of resources due to submergence by water projects relate to loss of forest land, agricultural land, dwellings and habitats of people, archaeological relics, communications, mineral deposits etc. The loss of resource *per se* cannot be avoided but can be minimized or compensated by remedial measures to be implemented before project construction. Resettlement of populations living in submergence areas is not a loss of resource as such, but is also discussed here because of the psychological stress caused by displacement.

4.1 Resettlement of displaced populations

The construction of reservoir projects brings in its wake the displacement of numerous persons from their hearth and home. The rehabilitation of displaced persons is really a crucial problem not only from the point of view of physical suffering of the people but also from the point of view of creating mental stress and strain in the displaced population. Though the social rehabilitation can never be perfect, it is necessary to ensure that the people are not worse off after rehabilitation than they were before. To minimize the problems, compensation should primarily aim at (a) providing the displaced persons with colonies having more modern facilities, (b) providing job opportunities to the displaced persons on a priority basis and (c) educating people for their active participation in the project activities.

The problems faced by the displaced population in many major project areas in India are being solved by the project authorities, by adopting various measures. To cite a few examples, the measures adopted or proposed in a few major projects in India are discussed below.

To assist the displaced people at Ukai Project (Gujarat), new village sites have been provided with approach roads, internal roads, schools, wells, drainage, etc. Facilities of communication have been given for seasonal cultivation. Displaced persons are given jobs on priority. Lift irrigation schemes on the reservoir fringes and cooperative fishing were also introduced. Industrial training in various crafts, hostel facilities and stipend were also provided.

The rehabilitation policy in respect of the displaced population of the future Narmadasagar Complex Project in Madhya Pradesh, proposes the following measures.

- (a) provision of land to displaced persons who will have to pay 50 percent of the compensation towards the cost. The remaining will be recovered in 20 yearly instalments.
- (b) cost of transportation of belongings.
- (c) payment of adequate compensation by liberalisation of the Land Acquisition Act to be guided by cost of land in the command area and not the submergence area where it is invariably less. Compensation will be paid 3 years before submergence.
- (d) plots for residential purposes to be allotted free to land holders as also others.
- (e) ex-gratia payment of Rs. 3 600 to landless labourers.
- (f) preference in provision of employment in project works to affected families.
- (g) exemption from payment of stamp duty and registration fee.

The project authorities propose to implement the above programmes by a separate Directorate consisting of four divisions: Land Acquisition, Resettlement, Rehabilitation and Training. Eminent sociologists have also been associated with the implementation programme and the district administration will be fully involved.

Similar measures are planned for the Sardar Sarovar Project (Gujarat) and some of the important measures planned are:

- (a) provision of a maximum of 2 ha of irrigated land and house sites (20x30m).
- (b) resettlement grants of Rs.750 per family.
- (c) grant-in-aid up to Rs. 500 in addition to compensation.
- (d) provision of civic amenities such as primary schools, drinking-water wells, primary health centres, etc. in resettlement colonies.

4.2 Destruction of upstream flora and fauna

The impoundment may submerge some forest land. From 1951 to 1980, an area of 0.52 Mha of forest land has been lost in the country due to the construction of river-valley projects. This is about 12 percent of the total forest land lost due to various reasons. The cutting of forests for other commercial and fire-wood purposes is the principal reason for major loss of forests rather than submergence by reservoirs. Further, there is considerable

tree growth that receives support in the command areas and along the reservoir shorelines and which improve the vegetal cover in the project areas.

The impoundment may also submerge wild-life habitats and sanctuaries. Submergence of wild-life habitats by the Dudhganga reservoir (Maharashtra) can be taken care of by relocating the sanctuaries in suitable places. In fact, abundant water supply in all the seasons is ensured to the wild life of the forests around reservoirs and this is a positive aspect of water resources development.

4.3 Submergence of mineral deposits and archaeological monuments and shrines

Another adverse effect of reservoirs can be the inundation of mineral deposits and archaeological monuments and shrines. A few such examples are cited below:

- (a) Khulisar limestone deposits being utilized for the Bokaro Steel Plant have been affected by the floods of the Choti Mahanadi River, a tributary of the Sone River (Bihar). Kutteshwar limestone deposits likely to be submerged to some extent by the Bansagar Lake (Madhya Pradesh) are being fully protected by providing a bund around the quarries at a cost of about Rs. 180 000.
- (b) A famous shrine of religious and historical importance situated in Sangam village at the confluence of the Rivers Malaprabha Krishna and Neelambika Temple at Tongadage village will be affected by the backwaters of Narayanpur reservoir (Karnataka) (Krishna Project 1976).
- (c) Large deposits of coal are liable to be submerged by the Panchet reservoir of DVC (Bihar). The full benefits of flood control cannot be achieved because of this constraint.
- (d) Some lead and zinc deposits are also likely to be submerged by the proposed Telugu Ganga Project.

It is possible to protect the mineral wealth situated along the shorelines of reservoirs by suitable protection measures such as ring bunds as proposed in the Bansagar project. The mineral resources falling in the reservoir bed can also be exploited, as far as possible, before inundation.

The Dargah at Galiakot was protected from submergence by a ring bund when the Kadana dam was constructed (Kadana Project 1969). The famous Nangarjunakonda Mahayana System of Buddhism consisting of valuable stupas, monasteries, inscribed pillars, sculptured slabs and other antiquities were excavated and the archaeological monuments have been shifted before impoundment to a museum on the top of a nearby hill. (Nagarjunasagar Project 1956).

4.4 Sedimentation of reservoirs

Sediment flow in rivers is a natural process depending on the erosion characteristics of watersheds. Water resources development projects do not contribute to any increase in the sediment flow in the rivers but the sediment is trapped by the reservoirs and this has a bearing on the effective storage available for regulation of river flows. A specific provision in the form of dead storage exists in all reservoirs to take care of this. In fact the dead storage space to be provided is being determined for reservoirs in India depending upon

standard reservoir types ranging from lake type to gorge type and sediment distributions are assessed to determine new zero elevations for positioning of outlets to draw water for various uses. Moreover, remedial measures to reduce the sediment flow in rivers are being taken by soil conservation and watershed treatment.

4.5 Reservoir induced seismicity

It is often claimed that the impoundment of water in a large reservoir triggers earthquakes (with their epicentre below or near the reservoir). Koyna dam (Maharashtra), 103 m in height and with a gross storage capacity of 2 796 Mm³ is cited in this connection but there is no conclusive evidence. The creation of a large reservoir with great depths of water has not induced any significant seismic activity in the case of Bhakra dam (Himachal Pradesh) 226 m in height and having a gross storage capacity of 9 621 Mm³.

A number of theories have been put forward to account for the seismic activity. These may be related to specific cases, and the conclusions drawn from them may not necessarily apply to other cases. The impounding of water may result in an alteration of the stress pattern in the rock beneath and near the reservoir. This change may be more significant if incipient weakness exists in the rockmass in the form of fissures and faults and presence of similar weak geological formations.

A study of 425 large dams in the world has shown that only in 15 cases were the seismic forces observed to have gone up after construction of the reservoirs. In 10 out of 15 cases the magnitude of the earthquakes was less than 5 on the Richter scale. The seismological observations established at Bhakra, Pong and Ramganga dams located in the Himalaya have not registered any increase in seismicity due to impounding of water in large reservoirs. There is need for more data collection in this respect before conclusions can be drawn. In India this is being done by the Indian Meteorological Department, the Central Water-Power Research Station at Pune and the School of Earthquake Engineering, Roorkee, which continuously monitor the seismic status of the area around some of the reservoirs.

5 Organizational and Legislative Measures to Mitigate the Adverse Impacts in India

The remedial measures to eliminate or to mitigate the adverse environmental impacts due to construction of water resources development projects have been discussed in the foregoing paragraphs. The organizational and legislative measures taken for the development of water resources projects, as a whole, as well as other remedial measures not mentioned above are briefly outlined below:

1. The Working Group constituted by the Ministry of Irrigation in 1980 (Ministry of Irrigation 1980), laid down comprehensive guidelines for preparation of detailed project reports on irrigation and multi-purpose projects to include, *inter alia*, environmental aspects. These guidelines include various important aspects such as site selection, physical and resources linkage aspects, socio-cultural and public health aspects etc. including data to be collected from the departments dealing with forests, fisheries, wild life, health, botanical and geological surveys, etc.
2. The National Board and the National Land Resources Conservation and Development Commission constituted by the Government of India under the Department of Agriculture in February 1983 is entrusted with comprehensive action plans on all aspects of land use in the country to achieve optimum returns from each source and maintain the ecological and environmental balance.

3. The National Water Resources Council constituted in March 1983 under the Chairmanship of the Prime Minister is to foster environmentally and economically sound development of water resources expeditiously in various regions. The Department of Environment has been entrusted with the responsibility of clearance of the projects from the environmental angle through its Environmental Appraisal Committee (Department Env't, 1982). As a precautionary measure, the project authorities have now been asked to incorporate a special chapter on environmental aspects in their project reports.
4. Private organizations such as the Centre for Science and Environment, New Delhi, are making continued efforts by extensively touring India to collect information on environmental aspects connected with various socio-economic development projects and have published Citizen's reports on the State of the Environment in India. Two such reports have been brought out by this organization, highlighting the environmental impacts with suggestions for remedial measures. (Citizen Report 1982, 89). The above efforts are indications of public awareness of environmental concern and their participation in efforts for environmental betterment in India.
5. The Central and state organizations in India are conducting refresher courses, seminars and workshops from time to time to focus on environmental aspects, methods for assessment of impacts and integration of impacts in planning of water resources development projects.

Besides the measures mentioned above, the Central Board of Water Pollution has also framed guidelines for controlling the concentration of pollutants which can be safely discharged by different industries into the rivers. Following suit, Water Pollution Boards in different states have also enacted suitable legislations to control water pollution.

The Central Board of Irrigation and Power has also initiated programmes under which various research stations in the states have taken up a number of research schemes on water quality and sedimentation aspects related to environmental impacts.

The Forest (Conservation) Act, 1980, has also been enacted with the sole objective of controlling indiscriminate use of forests for non-forest purposes. As a general policy, use of forest land for rehabilitation is not planned.

6. Conclusions

It is a foregone conclusion that the benefits which accrue from water resources projects and their adverse impacts on the environment cannot be viewed in isolation. The interests of development and environment need not necessarily be conflicting. What should be aimed at is sustainable development with the minimum adverse environmental impacts. The objective of all development projects should be to improve the socio-economic conditions of the region in harmony with the environment and the biosphere, stimulate the health and welfare of man and unleash the understanding of the economic system's natural resources so very important to the Nation. Where adverse environmental impacts are inescapable, it would be desirable to adopt an Environmental Impact Assessment procedure before the development schemes are taken up. A study of alternatives with the application of new technologies both for engineering feasibility and for a study of the impact on the environment is also suggested.

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PAPER 22

ENVIRONMENTAL ISSUES OF THE THREE-GORGE PROJECT: AN OVERVIEW

Liu Changming, Zuo Dakang²⁸

Abstract

This paper mainly deals with several issues on the environmental impacts of an ambitious project of building a high dam on the main course of the Changjiang (Yangtze River) sited at Three-Gorges. The tremendous effects of the project upon the natural and social environments are examined. On the basis of an overall review of the investigation conducted in recent years the author attempts to clarify the essential environmental impacts of the project.

I. Introduction

The idea of constructing the Three-Gorges dam in Changjiang (Yangtze River) valley was suggested first by Sun Zhongshan, a great founder of the Republic, in the 1920's. Some surveys were carried out in the 1930's and 1940's but after 1949, considerable survey work was carried out at the dam site by the engineers of The Changjiang Valley Planning Office, the Ministry of Water Resources and Electric Power, and scientists from various research institutes.

In 1954, there was a heavy rainstorm, resulting in a big flood in the valley. It was estimated that almost 17 million residents along the middle and lower reaches of the Changjiang downstream of the Three-Gorges suffered from the disaster and more than one million hectares of farmland were submerged to retard the flood. The loss due to this flood disaster estimated at over US\$ 10 x 10⁹. Moreover, the Beijing-Guangzhou railway traffic was suspended for about 100 days. This event led the people to consider the construction of the Three-Gorges dam in order to control such floods.

In 1956, the Changjiang Valley Planning Office started to formulate a plan for the Changjiang Valley in which the Three-Gorges dam scheme was involved. In 1958, the essentials of the Three-Gorges dam project were suggested by the Office. Since that time the survey work on the project has continued over the years.

In 1971, the Gezhouba dam project at Yichang downstream of the Gorges was started and the first generating unit was commissioned in 1979. Gezhouba is the first dam on the main course of the Changjiang. It will serve as a counter-regulation reservoir for the Three-Gorges reservoir and it is sometimes thought of as an early stage of the Three-Gorges dam project.

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Since the mid-1970's, China has had a tremendous demand for energy, particularly in its southern regions where exploitable coal is limited. The decision to construct the Three-Gorges hydropower station followed the building of Gezhouba dam, encouraged by the need to solve the energy problem. In 1983, the Changjiang Valley Planning Office prepared a research report on feasibility of the dam. The National Planning Commission examined the report in May, 1983, and the State Council approved the report for preliminary design in April 1984.

The preliminary design of the project was prepared by the Changjiang Valley Planning Office in March 1985. Groups of experts from the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, were consulted concerning the project in the last two years. A group of experts from the World Bank was invited to inspect the dam site in May-June 1986. Recently this ambitious project has become a major concern not only of the Chinese people, but also of friends from different countries of the world. Because of uncertainty as regards environmental issues and economic problems, the different opinions on the project have given rise to much controversy in recent years. Major questions under debate are how to clarify the issues of the environmental impacts of the project on a scientific basis.

II. The River Basin and the Project

As is well known, the Changjiang is one of the largest rivers in the world. Its length of 6 300 km ranks it third in the world after the Amazon (6 516 km) and the Nile (6 484 km), and its annual runoff of about 1 Tm^3 also ranks it third after the Amazon (7.18 Tm^3) and the Congo (1.323 Tm^3). The Changjiang has a drainage area of $1\,800\,000 \text{ km}^2$ accounting for almost one-fifth of China's territory. Its annual runoff makes up over one-third of the country's total streamflow. The annual flow of the river averages $30\,166 \text{ m}^3\text{s}^{-1}$ (Table 1).

In a high water year (1954) the mean discharge amounted to over $43\,000 \text{ m}^3\text{s}^{-1}$ while in a low water year (1960) the mean discharge was below $25\,000 \text{ m}^3\text{s}^{-1}$. The ratio between high and low water years is less than 1.8 which shows that the Changjiang's runoff is quite stable among the rivers in China. Obviously, the Changjiang is very rich and its excess water is available for export to the water-deficient area of North China through inter-basin transfer (Zuo, Biswas, 1983).

The river course traverses ten administrative regions (Qinghai, Tibet, Yunnan, Sichuan, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Shanghai municipality) and finally flows into the East China sea. About 347 million people live in the basin and cultivate an area of over 24 Mha of fertile land. Agriculture in the basin is well-developed, with a grain production of about 120 Mt and good harvests of cotton, oil-seed and various cash crops. The annual industrial output is about 184 500 million Yuan (Table 2).

The Changjiang is rich not only in water resources, but also in hydropower potential due to the runoff volume and big channel gradient of the river (Table 1). The Changjiang is by far the most powerful river in China with a hydropower potential of 268 020 MW accounting for 40 percent of the country's total of 676 050 MW. A large portion of the hydropower potential is distributed in the upper reaches, west of the Yichang, Hubei Province, and on its large tributaries (Table 3). According to a survey, the exploitable hydropower potential of the Changjiang amounts to 197 240 MW (1 027 Wh), representing over 53 percent of the country's total (Cheng, 1985). Obviously the development of the Changjiang's hydropower potential is of great significance for solving the energy problem in China.

Table 1: Major Hydrological Characteristics of the Changjiang Basin

River Reach	Drainage Area (Mkm ²)	Length of River (km)	River Fall (m)	River Gradient 0/00	Annual Depth mm	Rainfall Volume 10 ³ Mm ³	Annual Runoff Discharge (m ³ s ⁻¹)	Depth (mm)
Up-stream of the Dam	1.00	4 469	5 400	1 208	896	896	14 307	451
Down-stream of the Dam	0.8	1 831	40	0.022	1 292	1033.6	15 864	625
Basin	1.80	6 300	5 440	0.863	1 072	1929.6	30 166	529

Table 2: Main pointers of economic development in the Changjiang Basin

Region	Area (km ²)	Popula-tion (million)	cultiva-ted Land (Mha)	Paddy (Mha)	Irriga-ted Area (Mha)	Grain Produc-tion (Mt)	Indus-trial output (Yuan x10 ⁹)
Upstream of the Dam	100	129.7	9.22	3.99	4.20	(32.77)	33.18
Down-stream of the Dam	80	218.26	15.18	10.09	11.60	(82.88)	151.32
Basin	180	347.96	24.50	14.08	15.8	(115.65)	184.5

Note: Figures in brackets are estimated.

It is well-known that the Changjiang is the main waterway of South China. The navigable channels have a total length of 70 000 km of which about 30 000 km of river channel are open to motor ships. 10 000 t sea-going vessels can sail far up the main course. Moreover, the river is never frozen because of the warm subtropical climate. In China the Changjiang is known as the "golden waterway".

Table 3: The Hydropower potential of Major Tributaries

Reach	Upper Reaches						Middle Reaches		
	Main Course	Yalong	Ming	Jaining	Wu	Others	Xian	Han	Gan
Annual Flow (m^3s^{-1})	4 510	1 860	2 920	2 230	1 710	-	2 290	1 780	2 200
Power (MW)	92 000	34 000	49 000	15 000	10 000	48 000	5 000	11 000	4 000
%	34.3	12.7	18.3	5.6	3.7	17.9	1.9	4.1	1.5

The Three-Gorges (San Xia) consist of the Qutang Xia, Wu Xia and the Xiling Xia (in Chinese the word "San" is "three" and "Xia" is a gorge). They are located in a long canyon which lies in the lower section of the upper reaches (Figure 1). The 200 km long canyon begins at Baidicheng in Sichuan Province and ends at Nanjinguan in Hubei Province. In actual fact, there are many short gorges scattered along the canyon including the Three-Gorges. Several dam sites have been surveyed over the years since the project was first proposed. Recently, the Sandouping dam site has been recognized as the best one by the geologists and hydraulic engineers. Sandouping dam site is about 43 km upstream of the city of Yichang where the Gezhouba dam, completed in 1979, is located. The dam site lies to the east of the Xiling Gorge, near the outlet of the canyon. The Gorges will therefore be submerged by the reservoir after the high dam has been completed.

Proposed water surface elevations range from 128 m to 260 m. On the basis of careful comparisons, the competent authorities have retained normal water storage levels at elevations varying between 150 m and 180 m. Details of the dam project are given in Table 4.

If the advantages of the project are multiple, its drawbacks are the very high construction cost together with a series of negative environmental impacts inevitable with this type of endeavour.

III. Impact Identification

The environmental impacts are so complex that a wide field of problems must be considered thoroughly and systematically. These impacts differ from one project to another. In the case of the Three-Gorges dam project, a great number of environmental effects have been preliminarily examined by Chinese scientists and engineers. The effects and variables of the Three-Gorges project now being studied are as follows:

Figure 1: The Three-Gorges

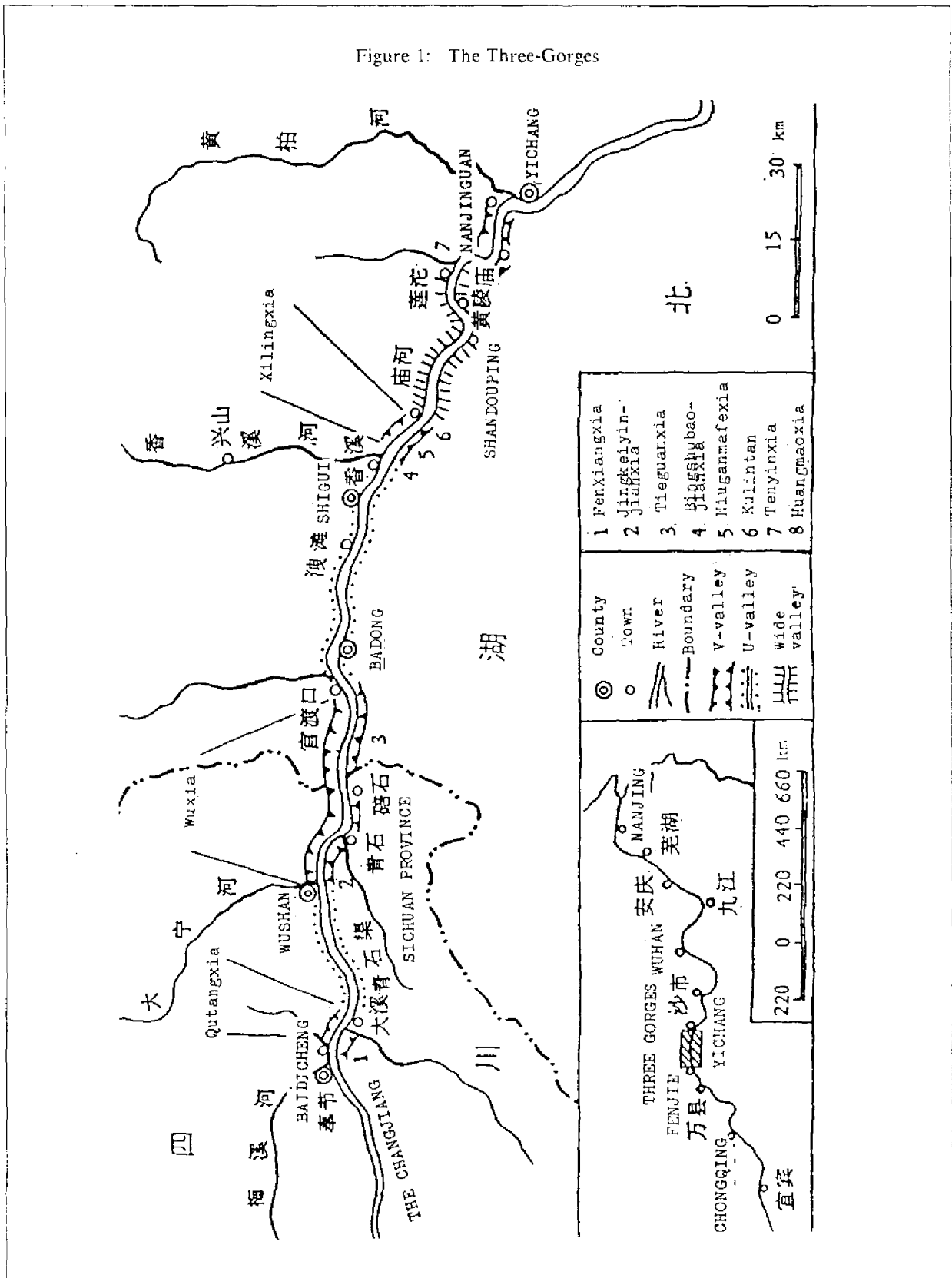


Table 4. The Three-Gorges Dam Project

Major Characteristics	Proposed Alternatives			
Normal storage elevation (m)	150	160	170	180
Elevation of dam crest (m)	175	175	175	175
Reduced elevation for flood reduction (m)	135	135	140	150
Flood control:				
Flood storage volume at normal Storage level (Gm ³)	7.29	13.8	19.7	24.9
Gross capacity of flood storage (Gm ³)	22.0	22.0	19.7	24.9
1000-year flood control (m ³ s ⁻¹)	71 700	71 700	75 700	76 100
20-year flood control(m ³ s ⁻¹)	56 700	56 700	56 700	51 700
Hydropower				
Installed capacity (MW)	13 000	14 820	16 900	18 720
Annual energy production (TWh)	67.7	73.2	78.5	89.1
Navigation:				
Improved Navigation Channel (km)	450-550	530-600	550-650	600-700
Submergence:				
Farmland (ha)	8 740	14 613	19 000	24 600
Displaced persons	330 000	420 000	620 000	768 000
Estimated gross investment: 10 ⁹ Yuan	15.95	17.20	19.88	22.08

1. Effects of the Three-Gorges project on the natural environment

1. Changes in micro-climate at the reservoir

a. air temperature

b. precipitation

- c. wind speed
- d. humidity
- e. fog density
- 2. Changes in water temperature and quality
 - a. low temperature stratification
 - b. pollutant diffusion
- 3. Changes in geology and geomorphology
 - a. induced earthquakes
 - b. bank erosion and landslides
 - c. mudflows
- 4. Changes in aquatic ecology
 - a. water ecosystem
 - b. aquatic life of rare and valuable aquatic fauna
 - c. fisheries
- 5. Changes of agricultural ecology
 - a. soil properties
 - b. agricultural patterns
- 6. Influence on flora in the reservoir basin
 - a. wild plants
 - b. valuable and rare plants
- 7. Influence on fauna in the reservoir basin
 - a. wild animals
 - b. valuable and rare animals
- 8. Changes of stream and sediment flow
 - a. reservoir sedimentation
 - b. flood drainage of upstream rivers
 - c. channel scour downstream of the dam

- d. lake regime downstream of the dam in the Changjiang middle reaches
- 9. Effects on the Changjiang estuary
 - a. channel erosion/sedimentation
 - b. ecology of the estuary and inshore areas
 - c. sea-water intrusion
 - d. soil salinization in the Changjiang delta
- 2. Effects of the Three-Gorges Project on Social Environment/Ecology
 - 1. Inundation and displacement of inhabitants
 - a. land loss
 - b. relocation costs
 - 2. Public health impacts
 - a. schistosomiasis (bilharzia)
 - b. malaria
 - c. other diseases
 - 3. Influence of the project on cultural heritage
 - a. historic relics
 - b. historic sites
 - c. recreation
- 3. On-site effects on the environment during dam construction
 - 1. Water pollution
 - 2. Air pollution
 - 3. Noise
 - 4. Landscape
 - 5. Sanitation in the construction areas

It can be seen that the various impacts related to the environment have been divided into in three groups: natural, social and on- site construction impacts.

Various specialists have carried out detailed work on specific environmental impacts and have obtained some preliminary results. These are useful for a better understanding of the changes in the environment that are likely to result from the Three-Gorges dam project.

In general, the environmental impacts can be classified in different ways. The magnitudes and importance of the effects on different variables of the environment are very distinct from one to another, and it is essential to separate the vital from the side issues.

According to magnitude and importance of the environmental impacts of the schemes proposed for the Three-Gorges project, a preliminary assessment has been carried out on the basis of the above-mentioned list. The results illustrate that the major environmental impacts may be classified in a descending order as follows:

1. Transfer of inhabitants from submerged area
2. Land loss due to inundation
3. Soil erosion
4. Sedimentation in the reservoir and upstream reach
5. Landslides and bank erosion
6. Induced earthquakes
7. Malaria spread
8. Damage to historical relics and sites
9. Damage to forest
10. Changes in customs
11. Waterlogging.

Items 8-11 are of significance only in the case of the 180 m dam and in fact the higher the dam, the greater the environmental impact. In addition, the vital impacts are found in the region of the reservoir and its neighbourhood. In comparison with these, other environmental impacts in areas far removed from the reservoir are likely to be less important.

IV. Major Environmental Impacts

From the geographical point of view, the environmental issues of the Three-Gorges dam project (150 m scheme) can be discussed by region (Liu, 1983).

1. The Reservoir Region

This region includes the reservoir itself and its immediate surroundings. The water surface at 150 m storage level would be 626 km². The submerged land area would amount to about 300 km² including 10 country towns, 374 small and medium-sized factories and about 10 000 ha of farmland. It is estimated that about 330 000 inhabitants would have to be moved from the inundated area. The cost of compensation would amount to at least 3.5 billion yuan. This excludes indirect loss in agricultural production such as a loss of orange groves located at elevations below 150 m. It is even more important to note that some very famous historical sites and relics would be submerged or damaged by the project. This would be an irretrievable loss to which is receiving serious attention on the part of the public in China.

An important opposition to the Three-Gorges dam project is related to the removal of the inhabitants from the reservoir area. This is a vital issue for the project's implementation. It is estimated that the 330 000 inhabitants would move mostly to higher land in the reservoir basin and that very few would move to places outside of the basin. Since this is a big upheaval in the life of the inhabitants, it is usually difficult to persuade them to move from their native place to unfamiliar areas. To solve this problem, a very high compensation will have to be paid to the people concerned. This can be arranged in different ways, although it is difficult to make definite proposals prior to examination of the project. It must be pointed out that the resettlement of inhabitants is a complex problem which involves a series of environmental impacts in the settlement area. The impacts to be expected are as follows:

1. Increase of population density in the resettled regions;
2. Intensification of land use;
3. Damage to flora and fauna, damage to forest;
4. Increase of pressure on food supplies;
5. Changes in social customs.

Migrations of populations are in themselves an environmental problem.

2. The Regions Upstream of the Reservoir

According to the dam design, the length of backwater upstream of the Three-Gorges dam will be about 500 km, reaching Changshou county. Sichuan province, about 100 km downstream of Chongqing, the largest municipality and river harbour in southwestern China. The areas affected by the backwater have a very high population density and there are numerous factories as well as fertile soils. The major environmental problems resulting from the project are: flood, waterlogging, sedimentation, changes in aquatic life and self-purification of polluted water.

1. Flood and waterlogging problems will take place in the Chongqing - Hechuan - Jiangin areas. If a storm results in a 20-year flood, the water level in the reservoir will rise and cause additional inundation requiring the temporary evacuation of about 4 000 inhabitants. Because the lower reaches of numerous tributaries would be inundated by the reservoir, their flood flows would be retarded resulting in waterlogging of the above-mentioned areas.

2. Sedimentation problems due to the reduction of flow velocities will result in deposition as far upstream as Chongqing. This will seriously influence about 300 km of navigable channel between the reservoir and Chongqing port although navigation conditions within the reservoir will be greatly improved.

3. The impact upon aquatic life will result mainly from the change from rapid streamflow to a static water-body and about 80 different species of fish living in free flowing water would migrate from the river section occupied by the reservoir. The Chongqing - Zigui - Jianglin reach is an important fry base for four Chinese native fish (*Genopharyngodon idellus*, *Mylopharyngodon plicatus*, *Hypophthalmichthys molitrix* and *Aristichthys nobilis*) which would disappear almost completely after completion of the project. Conversely, some species of lake fish would appear in the reservoir.

3. *The Region Downstream of the Dam*

This vast region consists of the middle and lower reaches as well as the estuary of the Changjiang. The length from the Three-Gorges dam to the Changjiang River mouth is over 1 830 km. The environmental impacts of the project vary in nature from one reach to another.

1. After completion of the dam project, a large quantity of clear water will be released from the reservoir. A section of river channel directly downstream of the dam is likely to be eroded and deepened. This channel deformation will gradually spread towards the Changjiang's middle reaches. According to research based on mathematical modelling conducted by the Hydraulic Research Institute of the Changjiang Valley Planning Office, 61-67 percent of the river sediments will be intercepted by the dam and channel deformation (erosion and deposition) processes in sections of the Changjiang's estuary are likely to take place. The study of this problem is in its initial stages and further investigations are needed before quantitative estimates can be made regarding this effect.

2. Much attention to impacts of the project upon the aquatic ecology of the Changjiang's middle reaches has been paid by the public in recent years. Some species of fish rare in both China and the world, such as *Acipenser sinensis*, *Psephurus gladius* (Chinese paddlefish), are only found in these reaches. It is clear that the aquatic environment would be changed by reservoir operation and these valuable and rare fish would be affected.

3. The problem of sea-water intrusion in the Changjiang estuary has been a problem for many years (Zhen et al., 1983). It is expected that no increase in sea-water intrusion will occur in the low-water season when the streamflow would be increased by 1 400 m³s⁻¹ released from the reservoir. Sea-water intrusion in the estuary will appear after the flood season in October, when the reservoir would start its accumulation phase. Salt-water intrusion can increase the rate of soil salinization in the Changjiang delta where the tremendous streams and channels are linked together and a network of high density is formed. Obviously, the intruding salt-water can affect large areas in the delta, particularly in Chongming county, Shanghai Municipality, and Nandong Prefecture on the north bank of Changjiang main course.

V. **Summary and Conclusions**

1. The Changjiang is the largest river in China, and one of the largest rivers in the world. Its water resources account for about 40 percent of the nation's total streamflow whilst its exploitable hydropower potential represents 53 percent of the national potential.

For this reason, the Changjiang occupies a decisive position in China's water resources development and any schemes involving its potential must be studied from the national viewpoint since excess water and energy can be exported to other regions. Full attention must therefore be paid to possible conflicting interests.

2. The merits of the Three-Gorges dam project aimed mainly at solving energy and flood problems are apparent to all. Inevitably, however, such activities also have unfavourable impacts upon the natural and social environment. In fact there are two sides to every project and this duality is magnified by the size of the project. Clearly, the 180 m storage level scheme has superior benefits but also more negative impacts than that of the 150 m scheme.

3. Geographically, the Changjiang is characterized by its enormous river length of 6300 km and its basin area of 1.8 Mkm². The environment of the basin differs from one place to another. The environmental responses to the project are quite distinct. From the geographical point of view, the environmental impacts of the Three-Gorges project can be analysed by river reaches, namely the reservoir reach and the upstream and downstream reaches. Such an analysis shows that the reservoir reach suffers from more environmental impacts than the others.

4. It is clear that the Three-Gorges dam project is an ambitious one for China and even at the world level. Due to its large scale, the environmental problems are so complex that numerous impacts should be considered concerning the natural environment and the social context. This complexity is discussed in this paper. Preliminary conclusions show that among the many impacts, the vital ones are the displacement of inhabitants, the loss of fertile lands and the sedimentation problems. Of course, this does not mean that the other impacts can be ignored.

5. Since this paper deals mainly with environmental issues, the great benefits of the Three-Gorges project are not described in detail. Generally speaking, they are likely to be very high in terms of flood control, electric-power generation, although opinions vary regarding the project. We believe that an integrated evaluation concerning the cost - benefit analysis should be carried out on the basis of systems analysis. For such an analysis, the environmental impacts of the project must be studied in advance.

The work of environmental impact assessment on the Three-Gorges dam project commenced in 1983. Many subjects of research remain for further study and the author thinks that no final decision concerning the project can be taken in the near future.

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PAPER 23

THE ENVIRONMENTAL IMPACTS OF IRRIGATION WITH SEWAGE WATER ON GROUNDWATER RESERVOIRS

Prof. Dr. Mostafa M. Soliman²⁸

Abstract

About forty percent of a Cairo's water supply is withdrawn from a groundwater reservoir located south-east of the Nile Delta. Several thousands of other shallow wells also supply drinking water for the farmers from the same groundwater reservoir, which is replenished by seepage from the Ismailia Canal, and the irrigation canal network, at the same location. Two sources of irrigation water are applied to this area: these are Nile water from the Ismailia Canal at the western border of the area and sewage water from an effluent located on higher ground adjacent to the eastern border of the same area.

It was found from the preliminary investigations that seepage from irrigation water of sewage origin contaminates a large part of the groundwater reservoir causing some social and environmental problems in the area.

In order to find a solution to this serious environmental problem, a groundwater model was set up to study the hydrodynamic conditions and to define a safe groundwater management plan in this location.

This paper is mainly concerned with the action taken to cope with the negative effects and the environmental conflicts due to the exploitation of contaminated groundwater.

Introduction

Part of the water supply for Cairo City is withdrawn from groundwater reservoirs. Unfortunately these reservoirs are believed to be contaminated by leakage of the sewage system of the city. In order to define the size of this leakage and its direction of motion a mathematical model is used, particularly for the north eastern part in view of its complexity.

The groundwater reservoir in this area is replenished from many sources which are: irrigation water which infiltrates through the soil; seepage from the irrigation canal network, and the rest from the water percolating from sewage spreading areas in the eastern side of the area as shown in Figure 1.

Two pumping stations, (WS (1), WS (2)) shown in Figure 1, pump water from the groundwater reservoir.

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There are also numerous wells driven by the farmers of the area to supply drinking water and serve irrigation requirements.

The purpose of the study discussed here is to determine the following facts:

- (a) The proportion of groundwater originating from sewage which is withdrawn by the two pumping stations WS (1) and WS (2), which negatively affects the water supply system.
- (b) The drainage effect, due to pumping from the aquifer, on the waterlogged areas in the vicinity of pump station WS (2), which is causing some environmental conflicts.

For these purposes a groundwater model has been built. A description of this model and its construction follows:

Groundwater Model

The steps involved in preparing a groundwater-basin model are:

- (a) The groundwater basin is subdivided into a mesh of sub-areas as shown in Fig. 2.
- (b) Geologic data are analyzed and transmissivity factors between zones and storativity factors within each zone or sub-area are determined.
- (c) Historical surface hydrologic data are analyzed and the net deep percolation for a given time increment suitable for the study period is obtained.
- (d) For each sub-area, the historical water levels during the study period are entered. A uniform water level is assumed across each sub-area.

The finite element method is used in this respect.

Discussion and Analysis

A computer programme was prepared based on the finite element method. The programme was run several times with different infiltration rates. One value was assigned first to the area and then various infiltration values were assigned for each geological zone. Each time the calculated piezometric heads from the computer programme were compared with the ones recorded in the observation wells. This procedure was repeated several times until finally the calculated piezometric contours coincided with the recorded ones. Once the contour lines had been drawn the flow net for the area was constructed. This enabled the identification of the catchment areas of the pumping stations and hence the areas recharged by sewage (Fig. 3).

It was found that the sewage recharge area feeding the Marg water supply station measures about 165 ha and henceforth the volume of sewage water that reaches this station is about $7\,810\text{ m}^3\text{ day}^{-1}$ or 44.6 percent of the total amount. Similarly the amount of sewage water which reaches Mustorod water supply station can be estimated to amount to less than 3 percent of the total quantity withdrawn from groundwater. This means that the water withdrawn from the two pumping stations should be carefully treated used for domestic supplies, at the same time reducing the negative effects due to contamination problems. On the other hand, the low-lying area near pumping station WS (2) was previously waterlogged, a situation which now results in many environmental conflicts. After pumping from that

Figure 23.1: Location Map

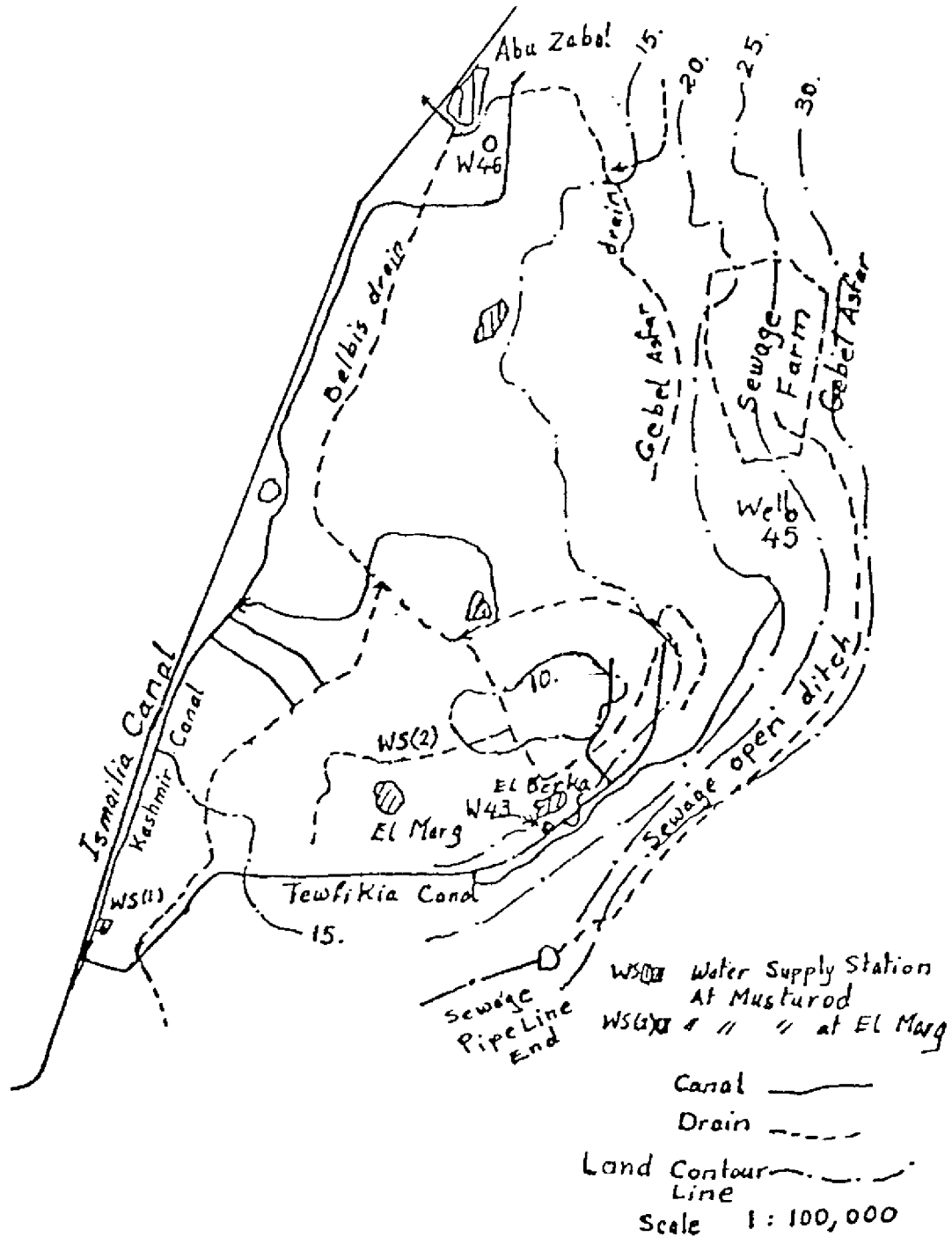


Figure 23.2: Finite Elements of Project Area East of Ismailia Canal

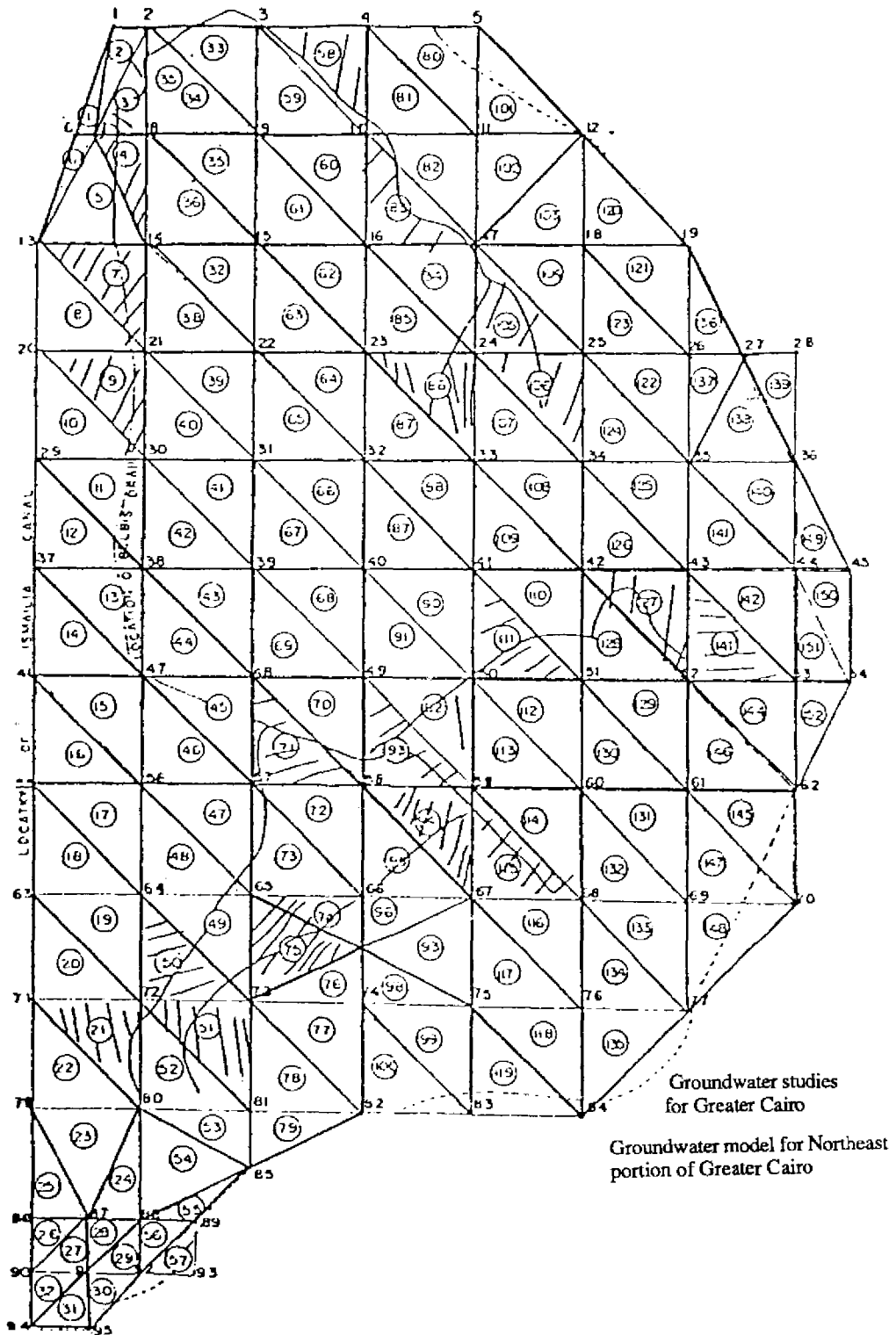
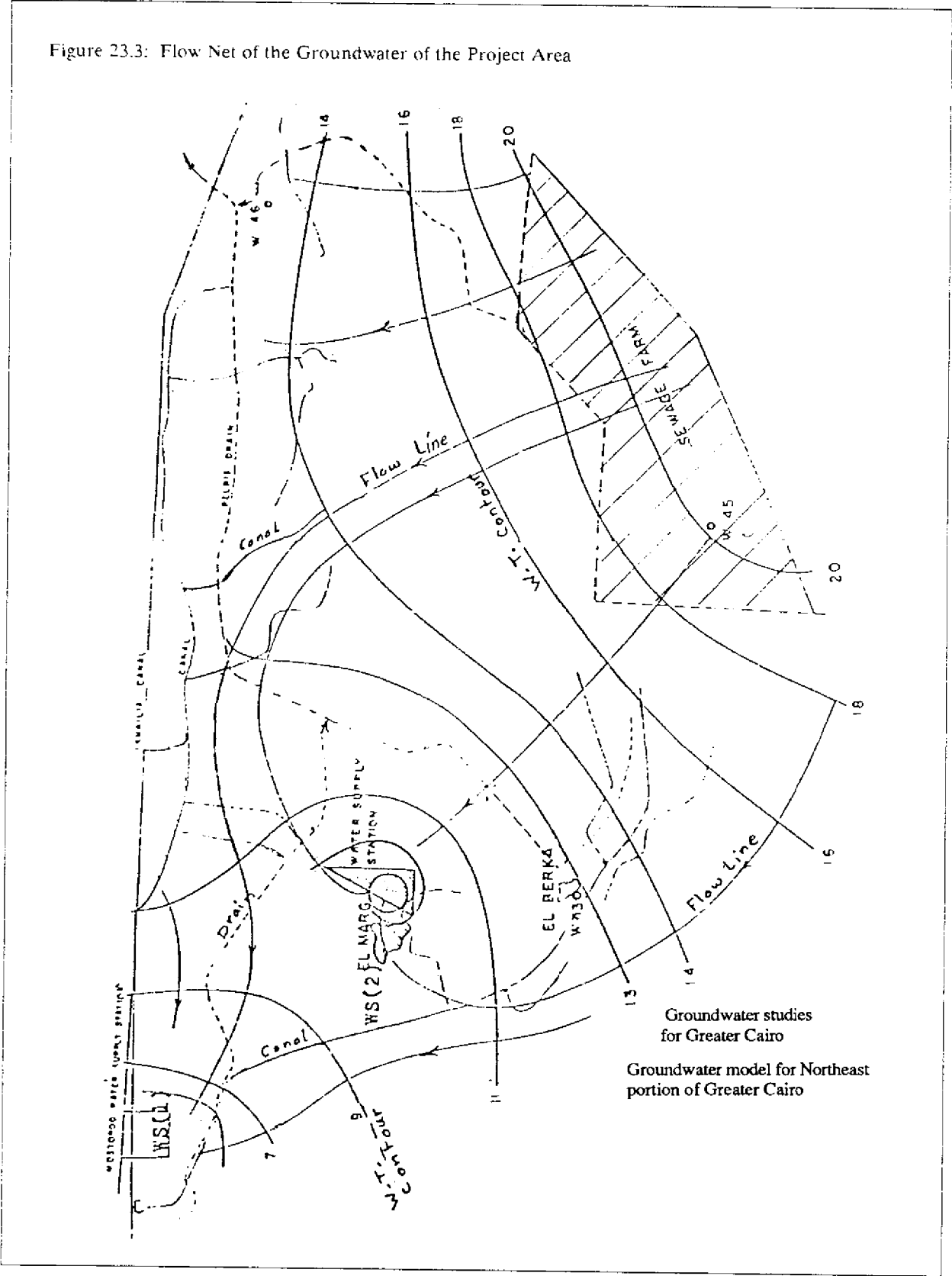


Figure 23.3: Flow Net of the Groundwater of the Project Area



station (which consists of 20 wells) the low-lying area was located within the groundwater catchment area of the station. This helped to lower the water table by one metre in the upper silty layer and changed the waterlogged area into cultivable land. It was also noted from the model analysis that pump station WS (2) intercepts a large proportion of the contaminated groundwater moving in the direction of the two stations, leaving a negligible proportion to be pumped by the main water supply station WS (1), which in this way receives protection from station WS (2).

As a conclusion it can be said that pumping station WS (2) intercepts the majority of the contaminated groundwater which seeps from the sewage farm, beside lowering the water table in the nearby waterlogged area. This has helped to mitigate the negative effects of contamination, besides solving other environmental problems.

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PAPER 24

IMPACT SUR L'ENVIRONNEMENT DES AMENAGEMENTS HYDRAULIQUES EN SAHEL FLUVIAL: FAUT-IL CONSTRUIRE LES BARRAGES SUR LE SENEGAL?

*Christian Reizer*³⁰

Résumé

L'Afrique, continent à cheval sur l'Equateur, bénéficie de climats tous chauds. L'eau est donc le principal paramètre régulateur des bioproductions.

Or l'eau pluviale, la plus immédiatement accessible, est très inégalement répartie sur le continent: abondante et régulière sous l'Equateur, elle se raréfie et irrégularise ses apports à mesure qu'on s'en éloigne.

Dès lors, les caractéristiques fondamentales du Sahel sont d'une part, vu son éloignement de l'Equateur, de ne disposer que d'une pluviométrie rare mais surtout irrégulière, d'autre part, de disposer d'eau superficielle abondante.

En particulier, les grandes plaines d'inondation ont été, sont et seront l'objet d'une sollicitude particulière des hommes.

La technologie traditionnelle vouait le lit majeur successivement à la pêche durant les hautes eaux, à l'agriculture durant l'exondation, à l'élevage (transhumant des terres sèches) durant l'étiage.

Cette disposition, en apparence harmonieuse, est battue en brèche par l'irrégularité de la pluviométrie interannuelle qui, suivant un cycle apparent d'une trentaine d'années, accuse des déficits marqués.

Les répercussions sur le système apparaissent d'une exceptionnelle gravité. Elles sont analysées.

Le sahélien riverain des grands fleuves a donc avantage, voire impérieuse nécessité à mettre en place une technologie de maîtrise hydraulique.

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Celle-ci consiste à, d'une part, accumuler l'eau de crue en barrages supérieurs, d'autre part, aménager l'espace lit majeur pour une maîtrise hydrique totale.

L'examen de la situation réelle sur les bassins les plus aménagés: Nil, Sénégal, conduit à observer que ce transfert de technologie est bénéfique pour l'agriculture mais très dommageable pour la pêche et l'élevage. Il y a donc un vice fondamental au transfert; les raisons en sont analysées.

Cependant l'examen plus approfondi démontre la possibilité de retrouver les trois spéculations ancestrales, sous réserve d'une information adéquate des décideurs.

Introduction

Il y a quelques années, C. Bessis publiait un article qui eut un retentissement considérable sur le grand public: "Faut-il construire les barrages sur le Sénégal?" (S. Bessis, 1981).

Comme ce titre le laisse présumer, l'auteur se posait une question fondamentale: l'aménagement des grands bassins inter-tropicaux, à travers l'exemple du Sénégal, ne coûte-t-il pas plus qu'il ne rapporte?

Dans l'esprit du présent colloque, nous avons choisi d'examiner le problème dans le cadre précis du Sahel "fluvial".

Notre intervention doit être considérée comme une réflexion issue des travaux de recherches que nous menons depuis 1966 dans cette région du monde.

Elle se structure en trois parties principales, relatives respectivement aux systèmes de production ancestral, contemporain et contemporain "amélioré".

Faire-valoir agronomique ancestral

Bases écologiques

Le Sahel fait partie de l'Afrique, laquelle, très succinctement se caractérise comme suit:

- c'est un continent distribué équitablement de part et d'autre de l'Equateur; dès lors, le paramètre bioclimatique majeur est l'eau, la température étant partout élevée;
- son relief général est tabulaire, sauf du côté des grabens orientaux; ses cours d'eau sont entrecoupés de chutes et de rapides ce qui génère potentiel énergétique mais difficulté de navigation;
- elle est massive, difficile d'accès de l'extérieur et d'un point à l'autre; elle a vécu repliée sur elle-même.

Le Sahel se développe en une bande parallèle, septentrionale et éloignée par rapport à l'Equateur. Son étalement en latitude est de quelques centaines de kilomètres. Son altitude moyenne demeure faible, sauf à l'Est; son relief se développe par grands paliers tabulaires.

Comme nous venons de le rappeler, l'eau est le paramètre bioclimatique le plus discriminant. Et, parmi les trois types d'eau douce, pluviale, tellurique-superficielle, tellurique-profonde, le premier est techniquement le plus accessible.

Or cette eau de pluie se distribue très différemment sur le continent, car elle est fonction du déplacement des grandes masses d'air. En substance, la zone équatoriale est abondamment arrosée, tandis que les zones tropicales le sont d'autant moins qu'elles sont éloignées de l'équateur.

Dès lors, le Sahel, extrême au plan géographique l'est aussi au plan climatique: sa pluviométrie est faible (250 à 600 mm an⁻¹).

La deuxième étape continentale de l'eau est la tellurique-superficielle. Or, le Sahel est justement drainé par de grands complexes fluvio-lacustres: Sénégal, Niger, Tchad, Nil. Ceux-ci enregistrent, en les aplanissant, les caractéristiques pluviométriques: leurs crues sont unimodales annuelles (Figure 1).

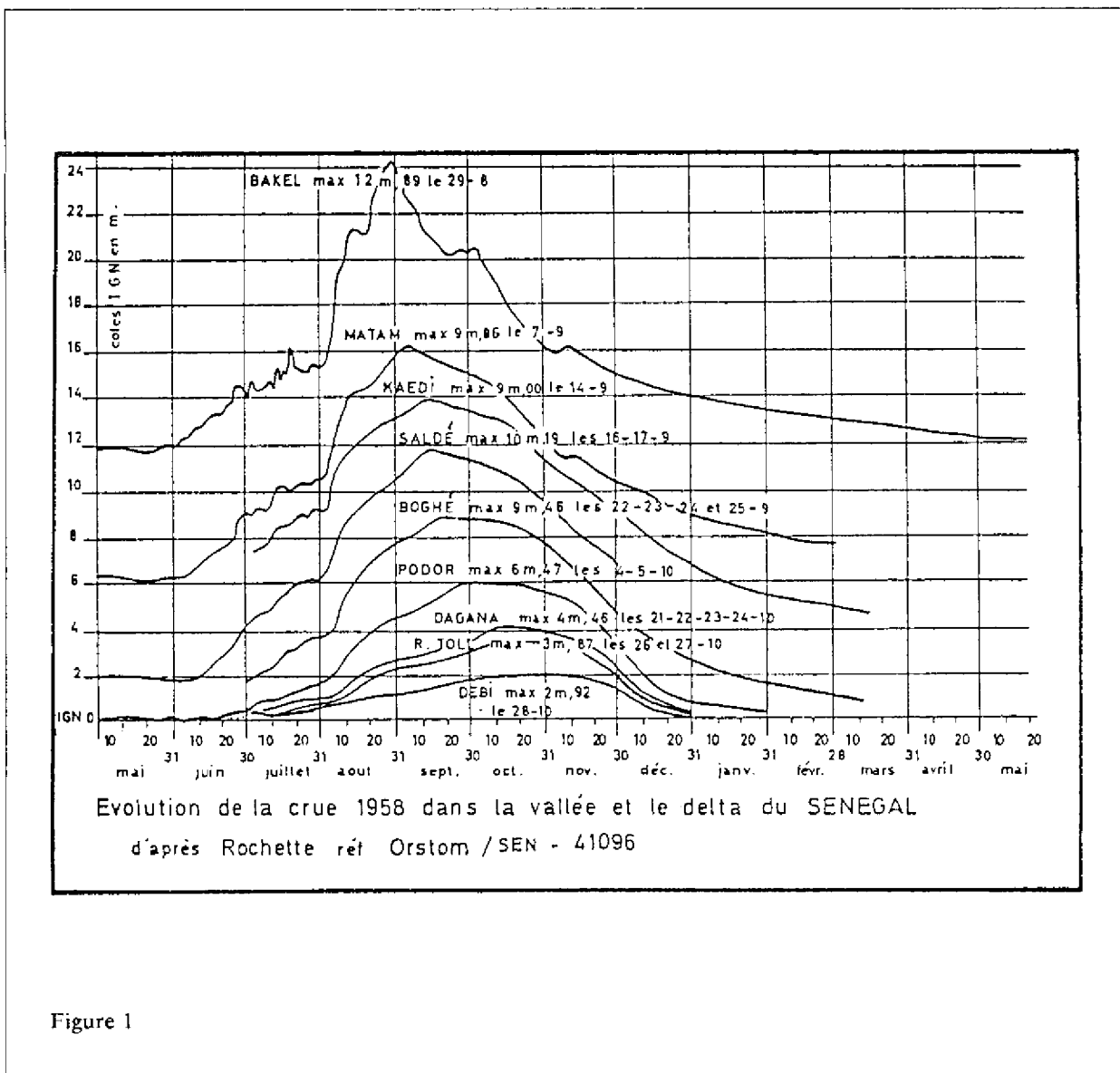
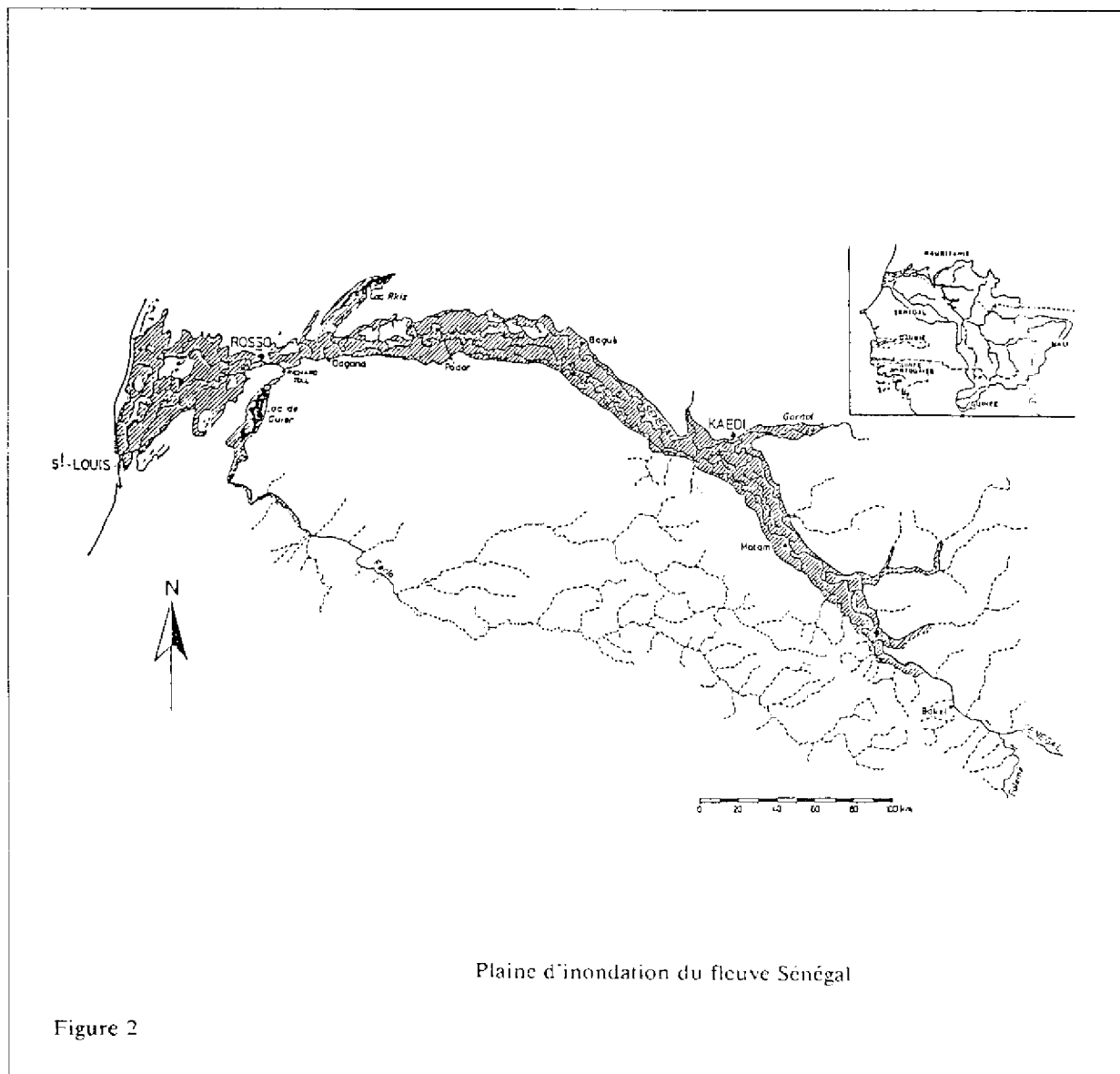


Figure 1



Autre particularité fondamentale, ces grands fleuves développent des plaines inondables importantes: 1.000.000 ha sur le Sénégal, 2.000.000 ha sur le Niger malien (Fig.2).

Conséquences agronomiques et culturelles

En Sahel fluvial (riverain des grands fleuves), les bio-productions sont les suivantes:

Hors plaines d'inondation

- Pâturages herbacés annuels, base de l'élevage bovin et ovin, du gibier;
- Forêts pérennes, base

- . du pâturage aérien des caprins, des camelins, du gibier,
- . de l'énergie : bois de feu;
- Agriculture vivrière.

Dans les plaines d'inondation

- Productions "terrestres"
 - . pâturages,
 - . forêts pérennes (pâturage aérien et énergie),
 - . Agriculture vivrière;
- Production végétale aquatique, base de la production piscicole.

Le maximum de complexité est atteint dans les plaines d'inondation, vu la proximité évidente des zones hors inondation.

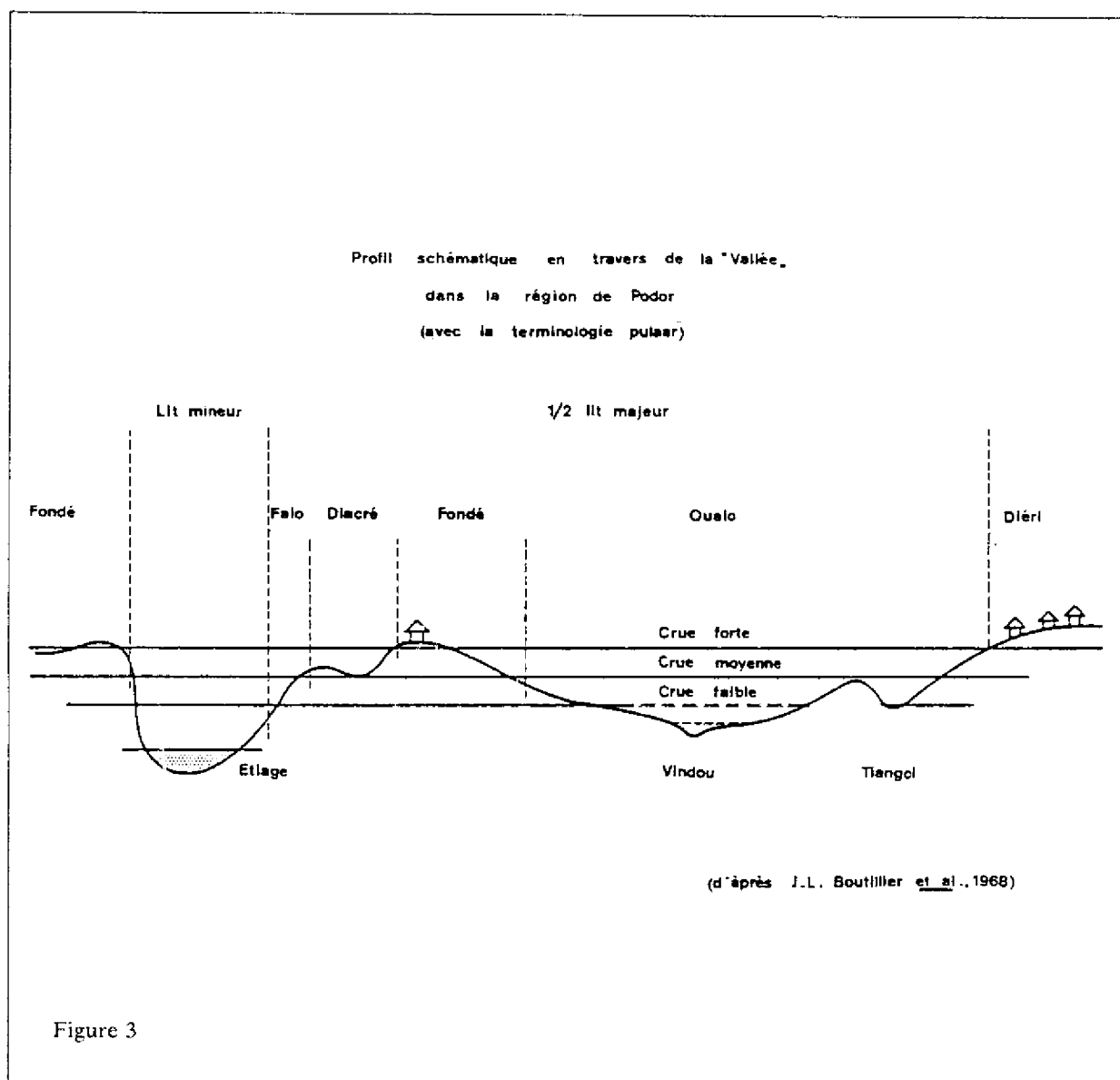
Trois facteurs agissent de façon rapprochée:

- le profil en travers (Figure 3);
- la crue: elle est univoque (Figure 1) et, sur le Sénégal et le Niger, uniquement déterminée par les pluies des hauts-bassins;
- la pluviométrie sur la plaine d'inondation est faible et coïncide avec la crue.

En conséquence, au plan des bioproductions de base:

- la végétation "terrestre" des abords (hors inondation)
 - . dépend de la pluie pour l'annuelle,
 - . est relativement indépendante de la pluie pour la pérenne;
- la végétation "terrestre" de la plaine
 - . dépend de la pluie (germination) et de la crue (croissance) pour l'annuelle,
 - . est relativement indépendante pour la pérenne;
- la production piscicole est totalement dépendante de la crue: la pauvreté intrinsèque des eaux est compensée par l'importance des surfaces inondées, leur faible profondeur, les hautes températures, le fumier animal (cf infra).

Dans cette région du Sénégal Moyen prise en exemple, les activités primaires essentielles sont: la pêche, l'agriculture, l'élevage, l'exploitation forestière; la chasse en tant que ressource a disparu. Les trois premières représentent, à parts égales, 90 pourcent du revenu. *Mutatis mutandis*, cette situation est comparable dans le Delta Central du Niger malien.



- La pêche: en règle générale dans les floodplains, et c'est le cas sur le Sénégal et le Niger, elle se caractérise par son niveau technique très élevé, capable de répondre à une demande stimulante, dès lors capable d'extraire la possibilité naturelle. En système traditionnel, aucune tentative de modification du milieu au bénéfice du poisson n'ayant eu lieu, l'espace lit mineur est occupé en étiage; l'espace lit majeur, durant la crue (août à novembre inclus).

- L'agriculture se distribue aussi sur deux territoires: le plateau hors vallée pendant la saison des pluies, la plaine inondée en décrue. Ces bioproductions dépendent donc des pluies locales pour les cultures sèches hors vallée, de la crue fluviale pour les cultures de décrue. En système traditionnel, l'agriculture modifie peu le milieu, si l'on excepte la préparation du sol avant l'inondation; l'espace hors vallée est occupé en saison des pluies (août à novembre); l'espace lit majeur, durant l'exondation (décembre à mars inclus).

- L'élevage occupe aussi une place importante. Il revêt ici deux formes:

l'une, sédentaire, en lit majeur: les animaux paissent sur les points hauts pendant la crue;

l'autre, transhumante, calquée sur l'écologie régionale:

en saison des pluies: dans le Sahel *stricto sensu* assez loin des fleuves, jusqu'à assèchement des mares;

en début de saison sèche: sur les chaumes des cultures sèches;

en fin de saison sèche (étiage fluvial): sur les chaumes des cultures de décrue et sur les prairies aquatiques.

En système traditionnel, aucune tentative de modification du milieu n'a lieu; l'espace est occupé de la façon décrite antérieurement et donc d'avril à juillet inclus pour ce qui concerne le lit majeur.

La forêt, résiduelle en floodplain, très claire en Sahel *stricto sensu* est utilisée soit comme pâturage aérien, soit comme source d'énergie.

Replacé ainsi dans son contexte global, le monde rural du Sahel "fluvial" pratique trois spéculations : l'agriculture, l'élevage, la pêche, l'espace "lit majeur" étant occupé successivement dans le temps par chacune d'entre elles (Figure 4).

Conclusion

Cette analyse conduit à la notion d'"enviroclimax", (écologique et humain) tellement le système global d'utilisation des floodplains met en évidence une harmonie certaine des hommes et de la nature. En fait, l'homme s'intègre à la nature plutôt que de la maîtriser.

Ces trois spéculations majeures s'enrichissent mutuellement:

- la pêche, indissociable du système en phase hydrique, "apporte" à l'agriculture et à l'élevage, par le biais des associations naturelles pâturées:

. limon et

. dissolution-activation du fumier animal ultra-sec;

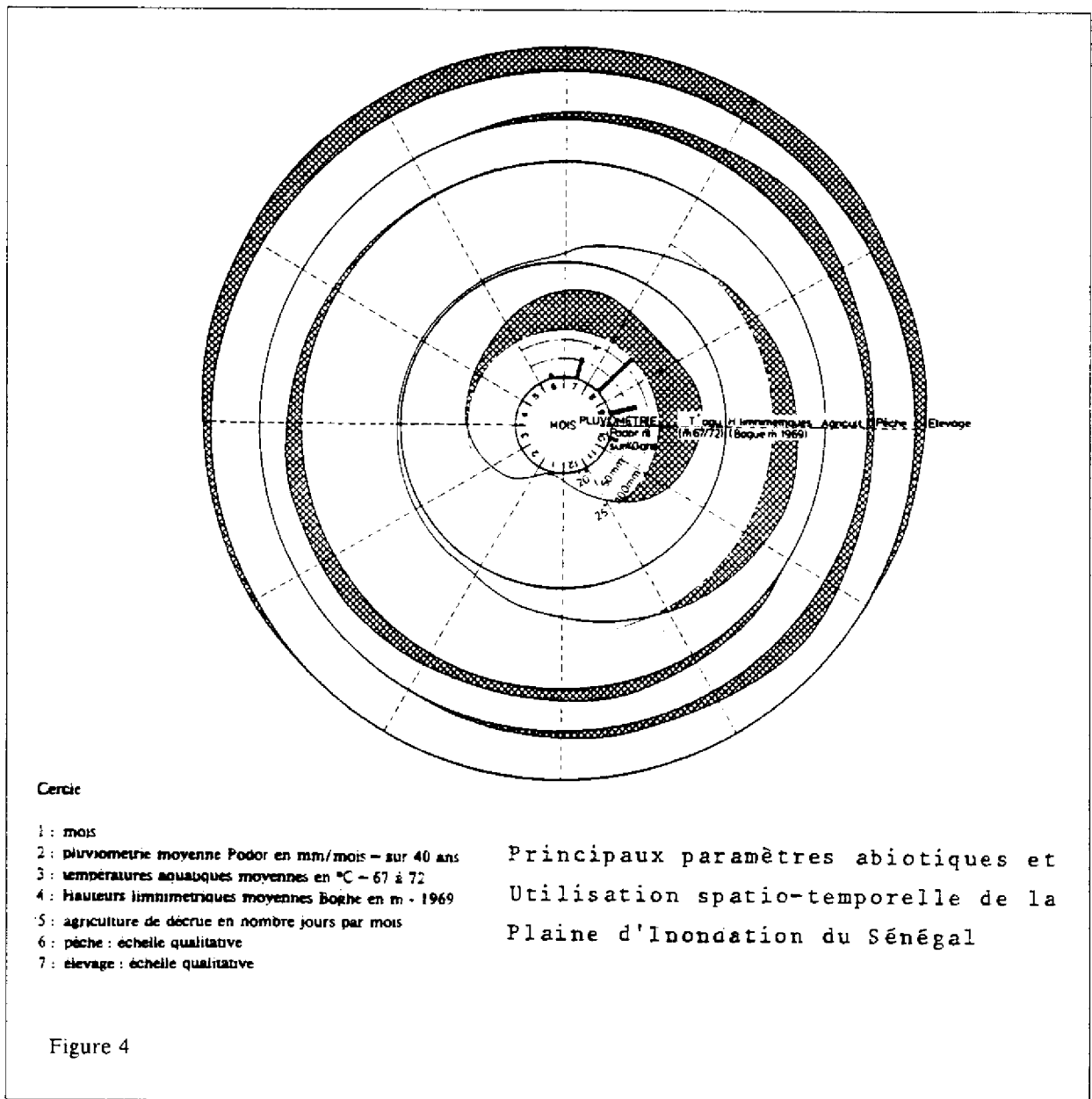
- l'agriculture apporte à l'élevage et à la pêche:

. ses résidus agricoles, dont les chaumes, soit pâturés, soit réintégrés au système hydrique;

- l'élevage abandonne au bénéfice de l'hydro-système pêches et de l'agriculture, du

. fumier en quantité.

La production piscicole notamment est régulée par trois paramètres principaux: l'inondation, certes par une eau souvent chimiquement pauvre mais d'un lit majeur important engraisé par des quantités de fumier animal sous hautes températures.



Alors tout ceci n'est-il pas harmonie? Où se situe le problème? et pourquoi les solutions "modernes" proposées?

L'observation suivante est fondamentale: La pluviométrie africaine non seulement diminue de l'Equateur aux Tropiques mais surtout s'irrégularise.

Les répercussions sur les crues fluviales quoique amorties, sont cependant d'une extrême importance (Figure 5).

Ainsi, sur le Sénégal Moyen et le Delta Central du Niger:

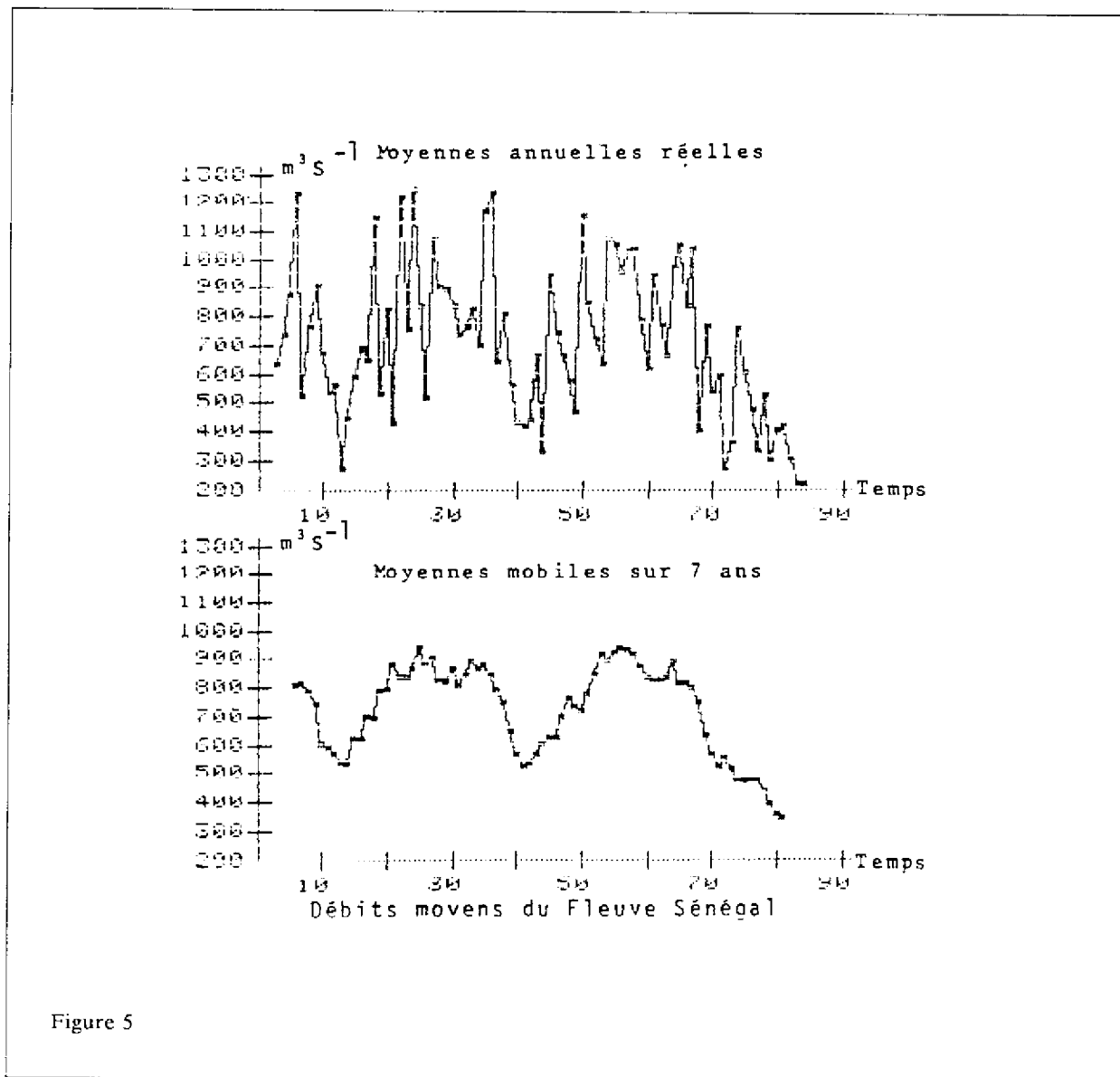


Figure 5

- les crues sont dépendantes des pluies sur le haut-bassin: elles n'existeront donc que si le Front Intertropical (F.I.T.), dans sa marche vers le nord, dépasse le Fouta-Djalon; - les pluies sur les floodplains n'existeront que si le F.I.T. atteint justement ces vallées. Dans ce cas, le F.I.T. dépasse donc nécessairement le Fouta-Djalon/haut-bassin et la crue a lieu.

La figure 6 illustre les différentes situations résultantes possibles. Il s'en déduit que la situation 1 est d'une particulière gravité. Or, elle est apparue plusieurs années de suite avec une périodicité apparente de 25 à 30 ans.

En fait, ce n'est donc pas la faiblesse de la pluviométrie (de la crue) qui est responsable des malheurs du Sahel, c'est son irrégularité. Car, même sous 100 mm de pluie, il demeure possible au paysan de faire pousser l'une ou l'autre plante sobre, à l'agronome d'inventer un

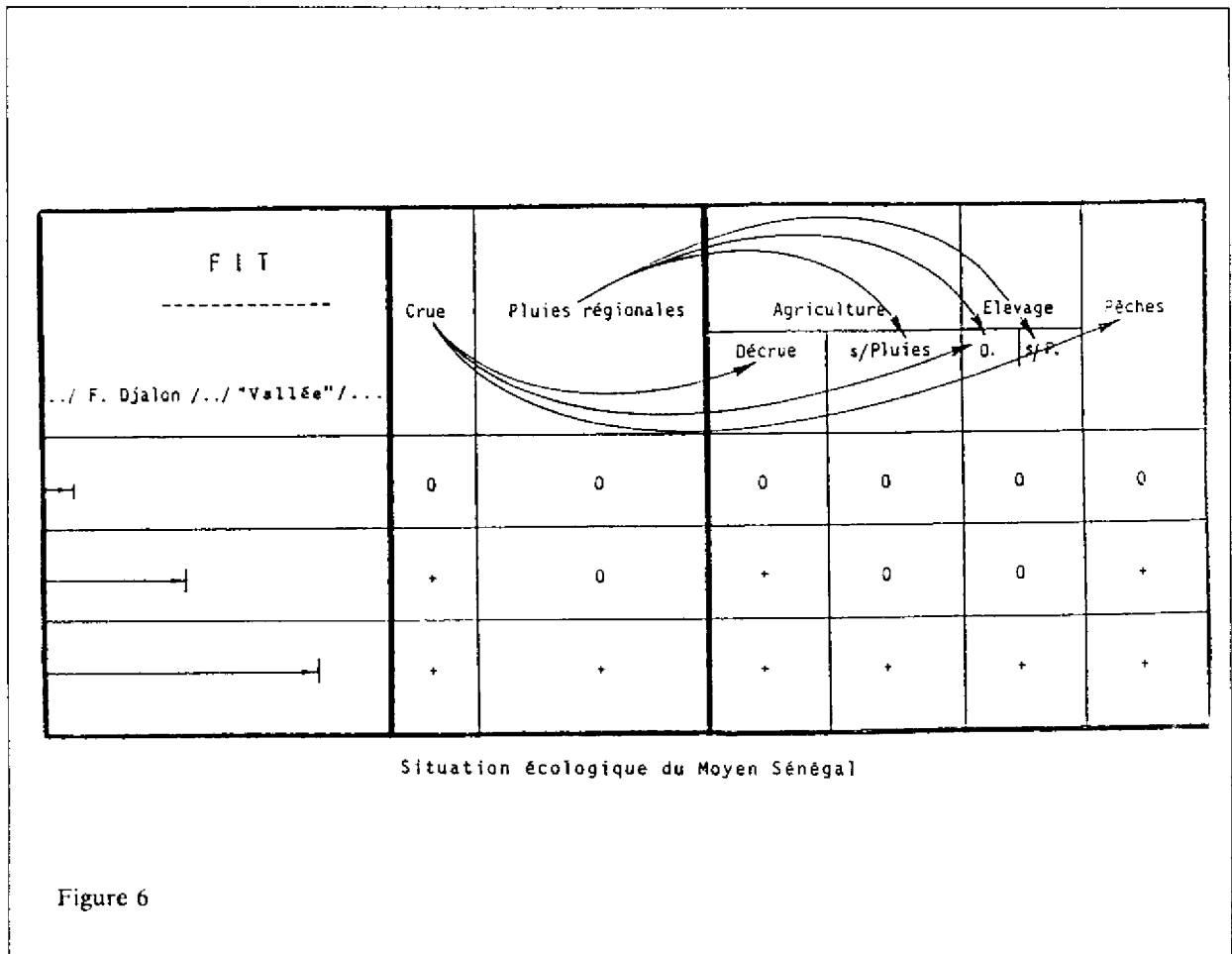


Figure 6

système suffisamment performant. Mais que faire quand on ne sait s'il pleuvra ou s'il ne pleuvra pas?

Dès lors quel est le choix des sahétiens en période de vaches maigres:

Mourir de faim? Migrer? où? Vivre de mendicité internationale?

Il y a donc ici un Sahel-Désespérance (C. Reizer, 1986) dû à l'irrégularité pluvio-fluviale interannuelle beaucoup plus qu'à sa faiblesse, dû à la succession des années de vaches grasses et des années de vaches maigres.

Et je vous laisse imaginer, l'homme ne maîtrisant pas la progression de sa propre multitude, l'impact prévisible sur l'environnement, lors de la prochaine décennie déficitaire au plan hydrique. De la réponse que nous donnerons aux éléments, dépendra ou non une nouvelle avancée du désert. Or si 30 ans est le temps d'un espoir c'est aussi celui d'un oubli.

Le Sahel est donc bien "extrémité" (du désert) comme le rappelle son nom.

Faire-valoir agronomique contemporain proposé

Ainsi donc le problème sahélien par excellence, son drame, naît non de la faiblesse mais de l'irrégularité interannuelle de la pluviométrie, de cette eau pluviale attendue directement par les cultures "sèches", et indirectement, via les fleuves, par les cultures de décrue.

La maîtrise de l'eau est donc ici toujours un avantage, sinon une nécessité.

Base : la maîtrise de l'eau

Ceci étant acquis, quelle eau maîtriser?

L'eau météorique? Nous venons de voir que la chose est impossible puisque nous n'avons pratiquement aucune possibilité d'action sur son système, lequel est de dimension semi-planétaire. Quel serait l'effet de la technique des "pluies artificielles" sur un ciel sans nuages?

L'eau tellurique-profonde? La maîtrise en est malaisée car impliquant pompage-profond, c'est-à-dire technologie avancée et adjonction d'énergie autre qu'humaine ou animale, donc coûteuse. Le puits est réservé à des usages restreints, boisson humaine et animale, et non à l'irrigation des champs ou des pâturages. Rappelons que, malgré les forages profonds dont est criblé le Ferlo sénégalais, pas une vache n'est morte de soif en 1972; par contre elles sont mortes de faim, l'eau du ciel ayant fait défaut pour la repousse des herbages sahéliens, l'eau fluviale ayant fait défaut pour la repousse des herbages aquatiques.

L'eau superficielle est finalement la plus accessible, même à des technologies peu avancées: par exemple, pour autant qu'il y ait lit majeur inondable, il suffit de suivre l'exondation pour réaliser une culture de décrue. Or, le Sahel est justement drainé par de grands complexes fluviaux Sénégal, Niger, Tchad au nord, Zambèze dans le sud, lesquels développent - encore - une plaine d'inondation temporaire.

C'est en fait la grande chance du Sahel que cette eau superficielle, ressource renouvelable et stockable.

Néanmoins, le système a ses imperfections: l'irrégularité de la pluviométrie entraîne une irrégularité conséquente du régime hydrique. A quoi la technologie contemporaine propose un système permettant de maîtriser cette eau superficielle:

- le stockage inter-saisonnier en retenues supérieures;
- l'aménagement des lits majeurs en aval.

D'autre part, nous avons dit aussi que le Sahel était doté d'un relief de type tabulaire; en conséquence, les grands fleuves régionaux sont entrecoupés de chutes.

Fait intéressant car la progression démographique d'une part, la rareté des sols fertiles d'autre part, oblige à l'intensification agricole, ce qui se traduit par l'injection d'énergie dans le système (engrais, mécanisation, etc...). Or, face à l'énergie pétrolière - fossile - l'hydroélectricité est renouvelable, réutilisable, propre et, sauf l'investissement initial, peu coûteuse.

C'est donc la chance du Sahel d'être drainé par des grands fleuves entrecoupés de chutes.

L'électricité sera d'abord produite "au fil de l'eau" (équipement du Félou sur le Sénégal, de Sotuba sur le Niger). Mais subsiste un inconvénient: la faiblesse des étiages. En conséquence, un stockage intersaisonnier s'avère intéressant, ce qui implique également la construction de retenues supérieures.

L'Afrique est massive, difficile d'accès par la mer, difficile d'accès d'un point à l'autre (côtes marécageuses, à falaises, fleuves avec chutes, grands déserts).

Ceci n'a pas manqué d'exercer une influence prépondérante sur les hommes: l'Afrique a longtemps vécu repliée sur elle-même en une série de civilisations distinctes centrées sur les "Grands Sahels Intérieurs" d'Hampaté Ba.

Mais n'est-ce pas là une chance pour l'Afrique, si de ce fait elle a préservé certaines valeurs fondamentales?

Seulement l'Afrique a ses exigences d'ouvertures à l'extérieur, d'accès à la "Civilisation de l'Universel" (A. Malraux, 1966). Notamment par la navigation fluviale.

En conséquence, le schéma d'aménagement des bassins se complète souvent par la création de barrages de reprise-écluses en lit majeur, ou de tout autre système favorisant la navigation.

Principes des aménagements

Les buts généralement poursuivis sont donc: le développement d'une agriculture moderne par irrigation, le développement d'une capacité industrielle par la mise à disposition d'une quantité d'énergie suffisante et à bon marché, l'amélioration de la navigabilité.

Le premier de ces buts ne sera atteint qu'avec des cultures intensives, ce qui implique une maîtrise totale de l'eau.

Le schéma général de l'aménagement sera en conséquence le suivant:

- barrages d'accumulation sur chacun des affluents de base;
- aménagement du lit majeur;
- parfois, barrages de reprise en lit majeur.

Les nombreux projets existant en Sahel le doteront ainsi d'une infrastructure considérable qui, vers l'an 2000, pourrait être décisive, parce que génératrice d'une production agricole croissante répondant aux besoins vivriers et agro-industriels; d'une triple production énergétique, propre, renouvelable: l'hydroélectricité, la bio-énergie par méthanisation des végétaux (résidus ou non) et le solaire.

Plus précisément pour ce qui concerne l'aménagement des plaines inondables, celles-ci sont généralement divisées en Unités Naturelles d'Équipement, constituant autant de parcelles de gestion hydrique (Figure 7).

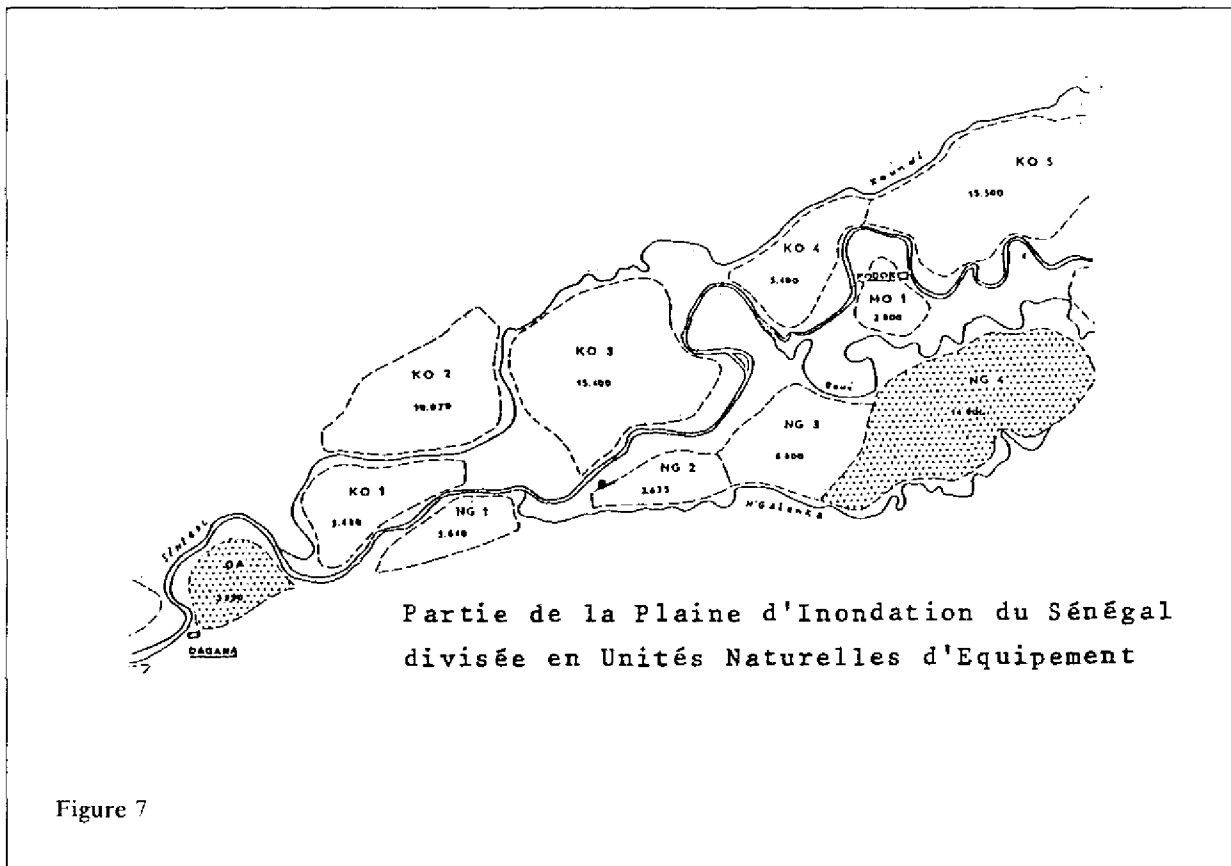


Figure 7

Conséquences agronomiques et culturelles

Barrage sur les Hauts-Bassins

L'effet sur l'environnement se traduit par le remplacement d'une surface de production agricole-forestière *stricto sensu* par une surface de production halieutique.

Le problème fondamental est le recasement des agriculteurs (et des forestiers) dont les terres sont inondées, mais bien plus encore leur reclassement professionnel en pêcheurs.

L'effet global est finalement bénéfique du fait d'une capacité globale supérieure à l'ancienne:

- d'une part, le lac produit de la protéine-poisson;
- d'autre part, il est loisible de développer sur la zone périphérique inondable, des cultures de type décrue;
- enfin, la forêt riveraine bénéficie d'un meilleur approvisionnement hydrique par le maintien d'une nappe phréatique proche et parfois aussi par un micro-climat plus humide.

Mais surtout, et ceci est une remarque fondamentale du point de vue que nous défendons ici, les productions agricoles et halieutiques sont sécurisées d'une année à l'autre, sauf vraiment exceptions, notamment, lors des grandes séries hydriques déficitaires.

Aménagement des lits majeurs

Les modifications du milieu sont tout aussi radicales: l'espace lit majeur inondable, occupé successivement durant un cycle annuel naturel par trois spéculations - pêche, agriculture, élevage - est aménagé au profit de la seule culture irriguée, et donc rendu indisponible pour les deux autres spéculations primaires.

L'impact est de ce fait:

- négatif pour la pêche; ainsi sur le Sénégal Moyen, 500 000 ha sur 600 000 ha étant soustraits à l'épandage de la crue, la perte en poisson sera de 30 000 t sur 36 000 t.

- négatif pour l'élevage; celui-ci est nécessairement transhumant, le troupeau résiduel n'ayant qu'une importance limitée; il est impossible, qu'on le sache bien, de maintenir les troupeaux en Sahel non fluvial durant tout le cycle annuel. Et les forages profonds n'y changeront rien, car s'ils apportent la boisson, ils n'apportent pas la nourriture adéquate en fin de saison sèche.

- positif pour l'agriculture; non seulement, les aménagements permettront une production céréalière importante, non seulement ils dotent les plaines des moyens de l'augmenter à besoin, mais surtout ils permettent de la régulariser au plan interannuel. C'est là d'ailleurs à notre sens, le résultat le plus positif: la sécurisation de la production alimentaire.

Dès lors, l'impact est tout aussi positif pour l'agriculteur à qui il n'est demandé que d'assimiler une modification technologique qui ne l'oblige pas à changer de statut professionnel: le passage des cultures sous pluie et de décrue à la culture irriguée.

Par contre, l'impact est éminemment négatif pour le pêcheur et l'éleveur qui y perdront emploi et raison d'exister.

Conclusion

L'approche globale des grands bassins intertropicaux conduit les aménagistes à proposer la maîtrise de l'eau superficielle tant pour l'agriculture et l'industrialisation que pour la navigation.

Le système proposé passe par le stockage dans des grandes retenues sur les hauts-bassins et l'aménagement des lits majeurs de l'aval.

L'impact se traduit par

- en amont: le remplacement d'une surface de production terrestre par une surface de production aquatique au droit des barrages supérieurs;

. la culture sous pluie peut être remplacée par la culture de décrue en périphérie,

. la capacité de production de poisson est augmentée.

Ceci pose le problème de la formation des pêcheurs.

- en aval: le remplacement d'une capacité d'utilisation annuelle triple successive - pêche, agriculture, élevage - du lit majeur par une capacité d'utilisation unique permanente, l'agriculture irriguée. L'impact positif est la sécurisation interannuelle de la *production agricole végétale*.

L'opération, cependant, débouche sur un paradoxe:

dans le système naturel, la ration alimentaire est bien équilibrée notamment sur le plan protéique, mais souffre d'insuffisance globale lors des soudures saisonnières et surtout lors des creux hydriques interannuels; l'emploi correspondant est diversifié;

dans le système proposé, la ration alimentaire est certes sécurisée, mais uniquement au plan céréalière, par contre, elle souffrira d'une carence protéique permanente due à la disparition de l'espace producteur de poisson et d'animaux terrestres (C. Reizer, 1984). Par ailleurs, le problème est d'autant plus grave que cette situation s'installe de façon insidieuse: il a fallu des siècles pour aménager la plaine d'inondation du Nil.

Il y a donc un vice profond au transfert de technologie.

Cependant, avant de crier au scandale, examinons d'un peu plus près le plan d'une Unité Naturelle d'Équipement, tel qu'il est proposé par les aménagistes.

Faire-valoir agronomique contemporain "amélioré"

L'examen du plan de finalisation de l'espace de l'UNE de Dagona prise en exemple, montre l'existence de zones classées "non aménageables":

d'une part, en position haute, la légèreté et le niveau des sols empêchent leur irrigation;

d'autre part, en position basse, la lourdeur et le niveau des sols empêchent leur drainage.

De notre point de vue, ces deux types de zones peuvent convenir à deux sinon à trois des spéculations traditionnelles. (Fig. 8).

Zones hautes

Certes les sols y sont sableux et donc filtrants, cependant la nappe phréatique n'est pas tellement éloignée de la surface du fait du plan d'eau quasi permanent des rizières de la zone d'altitude moyenne.

On imagine aisément un boisement de cette zone haute peut-être d'ailleurs à partir d'essences plus exigeantes en eau mais de meilleure venue que les essences sahéliennes strictes, l'eau tellurique compensant les insuffisances pluviométriques. La forêt y retrouve ainsi son compte.

Il n'est pas interdit en outre de penser à certaines formes d'élevage qui peuvent s'accommoder de ce type de végétation, serait-ce pendant une période limitée de l'année.

Reizer

Zones basses

Ces zones, à la topographie tourmentée, au sol argileux, occupent souvent l'emplacement d'anciennes mares.

Il est proposé de les transformer en grands étangs à niveau constant, non vidangeables, où pourra se pratiquer la pêche-pisciculture.

Ainsi seront sauvegardés et l'emploi des pêcheurs et la capacité de production de la protéine-poisson.

Zones moyennes

Celles-ci, de par la volonté des aménagistes sont vouées exclusivement à la culture *stricto sensu*.

Il demeure cependant qu'il serait intéressant d'en distraire certaines franges, pour les affecter soit à la culture fourragère d'embouche, soit à la pisciculture classique.

Conclusions

L'examen des UNE montre qu'il est possible d'y maintenir les quatre spéculations primaires originelles:

- l'agriculture irriguée en zone topographique moyenne;
- la pisciculture en substitution de la pêche en zone basse;
- l'élevage en substitution de l'élevage extensif en zone haute;
- la forêt intensive en substitution de la forêt extensive en zone haute.

Les remèdes techniques existent donc. Dès lors pourquoi ne sont-ils que rarement appliqués?

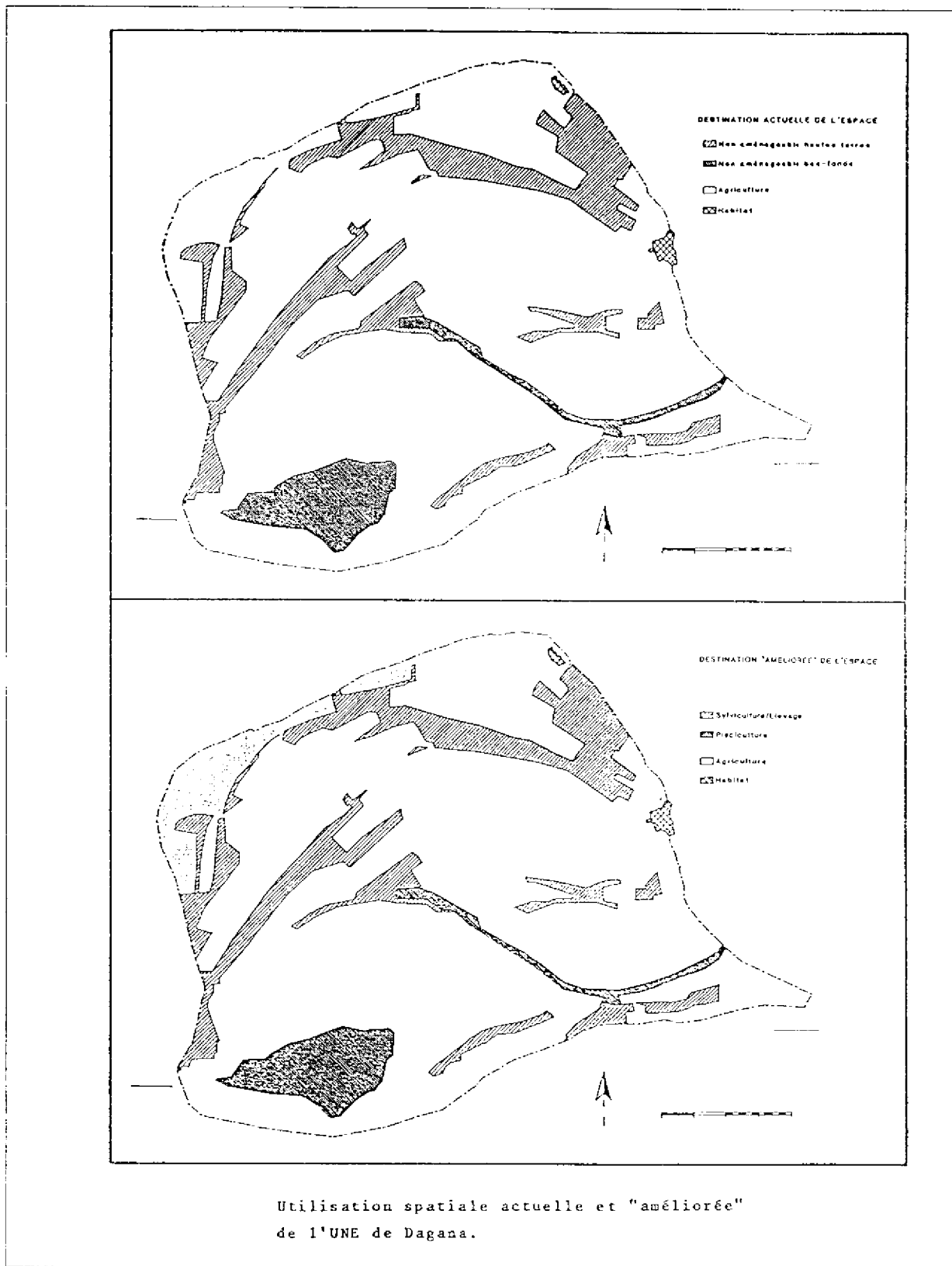
Selon nous parce qu'un mal profond accompagne le transfert de technologie: les décisions d'aménagement sont les plus souvent encore prises par des hommes unidimensionnels dans leur façon de concevoir.

Le remède est dans un complément de formation pluridisciplinaire, dans les études originales de développement intégré, d'éco-développement, faisant passer le décideur d'une vision monodisciplinaire à une vision pluridisciplinaire.

Conclusions générales

En conditions naturelles, écologie et anthropologie conjuguent leurs effets pour conduire à un Sahel-Désespérance, consécutif fondamentalement à l'irrégularité des apports pluviométriques.

La technologie de maîtrise des eaux superficielles courantes et stagnantes, abondantes en Sahel, en éliminant le paramètre limitant, l'eau irrégulière, laisse entrevoir le Sahel-Espérance. Sous réserve d'une information adéquate des décideurs.



En fait, le développement rationnel de la région intertropicale doit privilégier d'autant plus l'aménagement hydraulique des grands fleuves qu'ils sont plus éloignés de l'équateur et que l'eau est plus irrégulièrement distribuée.

Par ailleurs, ce raisonnement peut s'appliquer à toutes les grandes plaines d'inondation. Et on peut s'offrir la réflexion suivante qui met un point d'arrêt à notre discours.

Lieux de rencontre entre le sol, l'eau et le soleil, lieux de renouvellement de la fertilité, les plaines d'inondation intertropicales ont été de tous temps des centres privilégiés où se sont développées des civilisations brillantes. Légendaires - et sacrés - sont les fleuves qui les baignent : Sénégal, Niger, Nil, Zambèze en Afrique; Indus, Gange, Brahmapoutre, Irrawaddy, Mékong en Asie, Sepik en Nouvelle-Guinée; Orénoque, Rio Magdalena en Amérique du Sud.

Leur sort sera très certainement indentique dans l'avenir, du fait que se trouvent ici réunies les conditions de production de trois types d'énergies renouvelables et propres:

- l'énergie hydro-électrique (chutes, débits, capacité de stockage);
- l'énergie solaire (nombre important d'heures d'ensoleillement);
- l'énergie biomassique (eau, sol, limon, soleil).

Il n'y a dès lors rien d'étonnant à ce que les grands bassins intertropicaux soient l'objet de sollicitudes particulières. L'avenir du monde intertropical en dépend pour une très large part.

Cependant la condition *sine qua non* de la réussite du développement est une amélioration du transfert de technologies par le passage de la mono à la pluridimension, minimisant certains impacts négatifs remarqués actuellement.

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THEME II

**IMPACTS OF LARGE INTER-BASIN WATER TRANSFERS AND THEIR IMPLICATIONS
FOR WATER MANAGEMENT POLICIES**

PAPER 25

INCIDENCES SUR L'ENVIRONNEMENT DU PROJET D'AMENAGEMENT HYDRO-ELECTRIQUE DE LA BAIE JAMES

*Gaétan Guertin*³⁰

Résumé

Entrepris en 1972 pour se terminer cette année (1986), les travaux de mise en valeur des ressources hydrauliques de la rivière La Grande comprennent, entre autres, la construction de trois centrales, le détournement des eaux de deux rivières et la création de cinq réservoirs. Bien que le complexe La Grande ait techniquement été dispensé du régime de protection de l'environnement, le complexe a fait l'objet de plusieurs mesures de correction et d'aménagement visant à réduire les répercussions indésirables découlant du développement. Axés spécifiquement sur la surveillance des travaux de construction, sur la conception et la réalisation de mesures de mitigation et sur un programme de surveillance écologique, ces mécanismes de protection validés par des comités d'experts ont de plus permis une certaine mise en valeur de l'environnement. Encadrée par "la Convention de la Baie James et du Nord québécois" qui instaure un régime de protection de l'environnement et du milieu social et appuyée par son expérience de plus de douze ans sur le territoire, Hydro-Québec est prête à entreprendre la phase II du complexe La Grande.

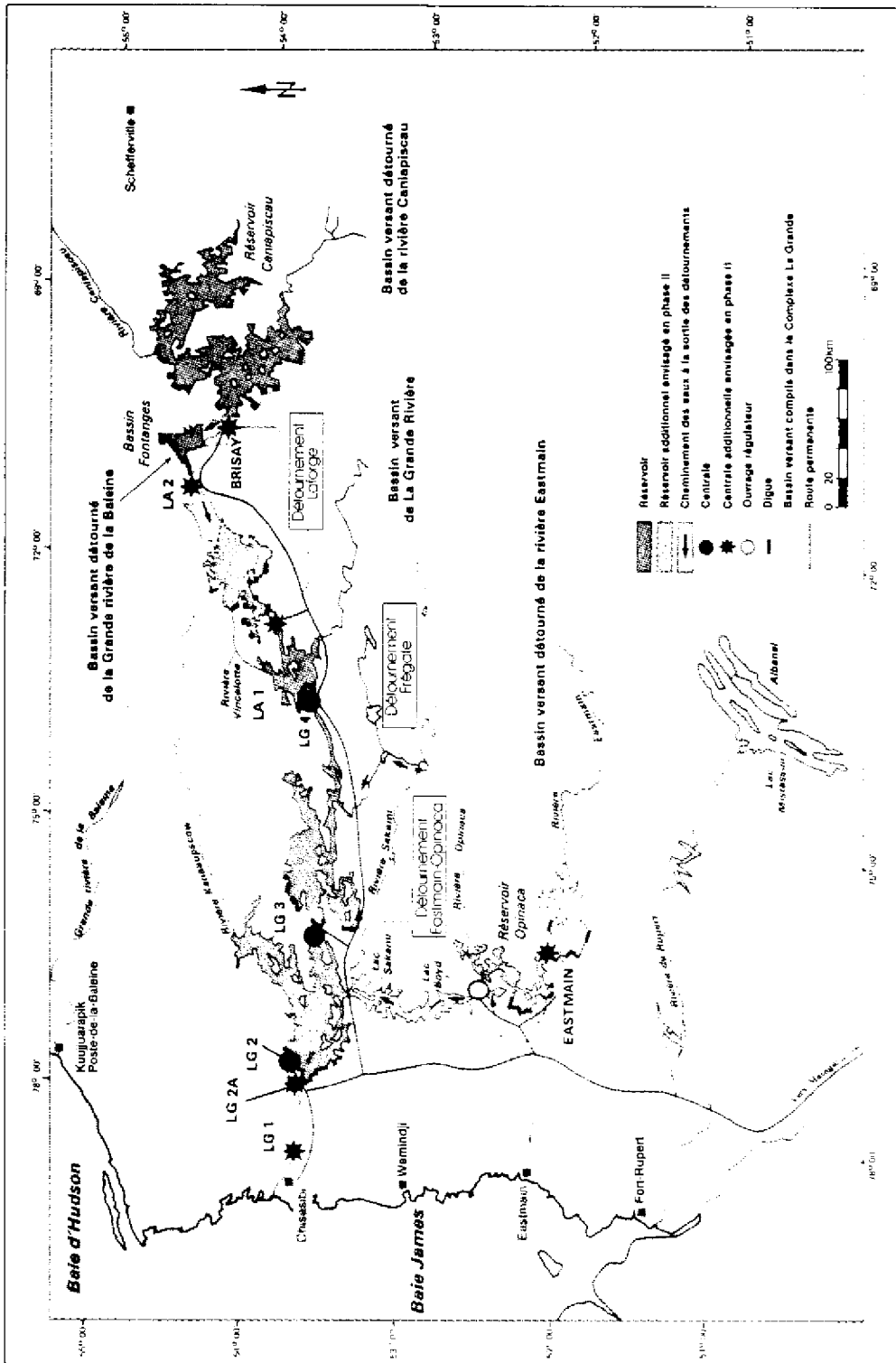
1. Le complexe La Grande en bref

Au début des années 70, pour répondre aux besoins en électricité des années 80 de la population québécoise, un projet hydroélectrique d'envergure allait être mis en place sur le territoire de la Baie James dans le Moyen Nord québécois. Les études d'optimisation permettent, en 1974, de définir le schéma d'aménagement qui, dans la Convention de la Baie James et du Nord québécois, a été désigné sous le nom du Complexe La Grande (figure 1).

A une époque où la qualité de l'environnement devenait de plus en plus une préoccupation sociale, la mise en valeur des ressources naturelles devait pouvoir se faire en assurant la protection du milieu et en respectant les aspirations de la population.

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Complexe hydroélectrique de La Grande Rivière



En aménageant le Complexe La Grande, la société d'Énergie de la Baie James (SEBJ)³¹ a dû trouver des solutions originales pour protéger le territoire de la Baie James tout en ajustant ses propres intérêts à ceux des populations amérindiennes désireuses de poursuivre leur mode de vie traditionnel.

Entrepris en 1972 pour se terminer cette année (1986), les travaux de la phase I de mise en valeur des ressources hydrauliques de La Grande Rivière comprennent la construction de trois centrales sur La Grande Rivière (LG2, LG3 et LG4) pour un total de 37 groupes, ainsi que le détournement, dans cette dernière, des eaux des bassins supérieurs des rivières Eastmain et Opinaca au sud et Caniapiscou à l'est. Ces deux détournements doublent presque le débit moyen de La Grande Rivière (3 400 m³s⁻¹ l'embouchure). Ce complexe, d'une puissance installée de 10 282 MW, peut produire plus de 62 TWh par an. (tableaux 1 et 2).

La mise en valeur de ce complexe a nécessité la construction de plus de 1 500 km d'infrastructure routière, la mise en place de 150 Mm³ de remblai pour ériger les 208 digues et 8 barrages totalisant près de 100 km de longueur qui retiennent les eaux de 11 345 km² de cinq grands réservoirs. Six campements ouvriers et cinq villages familiaux ont dû être créés pour héberger quelque 18 000 travailleurs en période de pointe. Le tout a entraîné des investissements de plus de 10 milliards de dollars canadiens (tableaux 3 et 4), sans compter 3,2 milliards pour le réseau de lignes de transport.

Lorsque s'amorça la construction du Complexe La Grande, de nombreux défis devaient être relevés. En effet, le projet s'inscrivait dans un milieu nordique hostile et peu connu où la période hors gel est d'environ 80 jours et la température moyenne annuelle est de -3°C. De plus, le territoire à aménager se trouvait distant de plus de 600 km de la plus proche voie d'accès terrestre et le projet impliquait des travaux d'envergure dans un vaste territoire de 170 000 km², où quelque 7 000 Amérindiens exploitaient les ressources fauniques à des fins de subsistance.

La deuxième phase de construction du Complexe La Grande comprendra l'aménagement de cinq centrales supplémentaires (LG-1, Laforge 1, Laforge 2, Brisay, Eastmain), garantissant ainsi une puissance annuelle supplémentaire de 18,5 TWh avec ses 26 groupes, en plus de l'énergie de pointe fournie par la centrale à LG2A avec ses 6 groupes de type Francis.

2. Les mécanismes de planification et de contrôle environnemental

Pour assurer l'intégration des préoccupations environnementales à toutes les étapes de réalisation du complexe, un certain nombre de mécanismes furent mis en place.

³¹ La Société d'Énergie de la Baie James a été créée en 1971 en vertu de la loi sur le Développement de la région de la Baie James. Elle avait alors pour mission d'aménager le potentiel hydroélectrique du territoire de la Baie James, d'exploiter et d'assurer le transport et la distribution de l'électricité dans ce territoire. En 1978 et en 1982, de nouvelles lois sont venues modifier le mandat initial de la SEBJ pour en faire une société de gérance de grands travaux. Filiale d'Hydro-Québec, la SEBJ continue d'assumer les travaux de développement des ressources hydroélectriques de la phase I du Complexe La Grande.

Ainsi dès le début, un groupe "Environnement" est inclus dans l'organigramme de la SEBJ, constitué d'une cinquantaine de spécialistes et techniciens en diverses sciences de l'environnement; ce groupe est désigné pour veiller spécifiquement à la protection et à la mise en valeur de l'environnement. Ses réalisations sont prestigieuses: participer à toutes les décisions concernant le projet, intervenir dans la conception des ouvrages, surveiller la construction, corriger certains impacts et contribuer à l'aménagement rationnel du territoire.

TABLEAU 1
FICHE TECHNIQUE DU COMPLEXE LA GRANDE

	LA GRANDE- PHASE I	LA GRANDE- PHASE II
DISTANCE À VOL D'OISEAU DE MONTRÉAL (km)	(À LG 2) 960	(À LG 1) 967
BASSIN HYDROGRA- PHIQUE AMÉNAGÉ (km ²)	176 810	VOIR PHASE I
CHUTE TOTALE AMÉNA- GÉE (m)	336	+26 (352)
DÉBIT MOYEN À L'EMBOUCHURE (m ³ s ⁻¹)	3 400	VOIR PHASE I
NOMBRE DE RÉSERVOIRS	5	3
RÉSERVE UTILE (10 ⁹ m ³)	94,3	10,9
SUPERFICIE (km ²)	11 345	2 018
NOMBRE DE CENTRALES	3	6
NOMBRE DE GROUPES	37	32
PUISSANCE INSTALLÉE (GW)	10,3	5,5
PRODUCTION ANNUELLE (TWH)	62,2	18,5
RÉSEAU ROUTIER (km)	1 500	+222 (1 722)
NOMBRE DE DIGUES ET DE BARRAGES	216	98
VOLUME DE REMBLAI (10 ⁶ m ³)	150	19

TABLEAU 2
LES CENTRALES DU COMPLEXE LA GRANDE - PHASE 1

	CENTRALES			
	L62	L63	L64	EOL
TYPE	SOUTERRAINE	EN SURFACE	EN SURFACE	
DISTANCE DE L'EMBOUCHURE (km)	112	238	463	
CHUTE NOMINALE (m)	137,2	79,2	116,7	
TYPE DE TURBINE	FRANCIS	FRANCIS	FRANCIS	
NOMBRE DE GROUPES	16	12	9	
PUISSANCE INSTALLÉE (GW)	5,3	2,3	2,7	
PRODUCTION ANNUELLE (TWH)	35,8	12,3	14,1	
DÉBIT MOYEN TURBINÉ ($m^3 s^{-1}$)	3 400	2 050	1 505	
MISE EN SERVICE	1979-81	1982-83	1984-85	
				SANS OBJET
				SANS OBJET

TABLEAU 3
 LES RÉSERVOIRS DU COMPLEXE LA GRANDE - PHASE 1

	RÉSERVOIRS				EOL
	LG2	LG3	LG4	CANIAPISCAU	
NIVEAU MAXIMAL (m)	175	256	377	536	216
NIVEAU MINIMAL (m)	168	244	366	523	212
SUPERFICIE (km ²)	2 835	2 420	765	4 285	1 040
RÉSERVE UTILE (10 ⁹ m ³)	19,4	25,2	7,2	39,1	3,4
NOMBRE DE BARRAGES	1	1	1	2	3
LONGUEUR DU BARRAGE (km)	2,8	3,8	3,8	5,5	4,9
NOMBRE DE DIGUES	29	67	12	91	8
LONGUEUR DES DIGUES (km)	23,8	22,9	5,8	51,0	6,0
MISE EN EAU	NOV. 78	AVRIL 81	MARS 83	OCT. 81	JUILLET 79

TABLEAU 4
LE COMPLEXE LA GRANDE - PHASE I: STATISTIQUES D'INTÉRÊT

	AUTRES DONNÉES				
	L62	L63	L64	CANIAPISCAU	E0L
DISTANCE À VOL D'OISEAU À MONTRÉAL (km)	960	900	925	1 075	825
VOLUME TOTAL EXCAVÉ ($10^6 m^3$)	32,0	26	9,2	19,8	3,8
VOLUME TOTAL DE REMBLAI ($10^6 m^3$)	47	35	33	35	6,7
BÉTON UTILISÉ ($10^6 m^3$)	0,5	0,5	0,3	0,1	0,08
EXPLOSIFS UTILISÉS (t)	21 363	16 900	4 500	32 000	3 080
CARBURANT CONSOMMÉ ($10^6 l$)	495	305	230	385	52,0
NOURRITURE CONSOMMÉE (t)	30 000	26 000	16 000	17 000	5 560
EFFECTIF DE POINTE	6 800	4 460	3 200	3 120	1 570
CAMPMENTS / VILLAGE	2/1	3/1	1/1	5/1	3/1

Au siège social, ces spécialistes participent à l'analyse et au choix des variantes d'aménagement et évaluent les répercussions sur le milieu. Ils interviennent quotidiennement dans le suivi de l'ingénierie et révisent les documents d'appel d'offre afin de s'assurer que les directives particulières de protection de l'environnement soient incluses aux clauses contractuelles. Les recommandations d'environnement ont été discutées avec les ingénieurs par l'intermédiaire d'un comité mixte Environnement-Ingénierie.

Sur le territoire, une équipe de surveillance est chargée de veiller à l'application des directives d'environnement et à la conformité des travaux avec des clauses particulières de protection du milieu. Tous les chantiers sont soumis à un contrôle journalier exercé par des responsables de l'environnement qui séjournent en permanence sur le territoire.

De plus, une vingtaine d'écologistes et de biologistes travaillent à partir du camp du lac Hélène, situé à 64 km de LG2, à la connaissance et au suivi de l'évolution du milieu avant et après la mise en eau des ouvrages.

Enfin, pour s'assurer que toutes les actions menées par l'équipe environnementale correspondent bien aux objectifs du mandat qui lui a été confié, un comité d'experts en environnement est créé afin de recueillir les opinions ainsi que les recommandations de spécialistes en environnement extérieurs à l'entreprise. Ce comité inclut des représentants des populations autochtones ainsi que des spécialistes dans différents domaines de l'environnement.

3. Les négociations avec les autochtones

Lorsque l'on a commencé à aménager le Complexe La Grande, 8 000 Autochtones (Cris, Naskapis, Inuit) y étaient répartis dans une dizaine de villages. La réalisation du complexe a eu de profondes répercussions sur la structure de leur société. La SEBJ a dû ajuster ses propres intérêts à ceux des populations amérindiennes désireuses de poursuivre leur mode de vie traditionnel.

Le contexte social

Avant même que l'on commence l'aménagement du Complexe La Grande, la société autochtone était déjà en pleine mutation et la population s'était peu à peu sédentarisée. Les activités traditionnelles (chasse, pêche, cueillette, piégeage) n'étaient plus pratiquées aussi intensément sur l'ensemble du territoire. Les structures sociales se transformaient et les nouvelles valeurs importées du Sud prenaient de plus en plus d'importance.

Les villages amérindiens étaient constitués en réserves, sous la tutelle du ministère canadien des affaires indiennes et du Nord. Ils étaient donc gérés pas des fonctionnaires et la bureaucratie blanche était présente dans tous les aspects de la vie de cette société.

Contesté au début par les populations autochtones de la région, le projet a pu être réalisé grâce à une entente signée en 1975, "la Convention de la Baie James et du Nord Québécois" qui, complétée par une série de textes législatifs, confère des droits précis aux autochtones, leur reconnaît une autorité et des pouvoirs administratifs et réglementaires dans des domaines qui les concernent directement, et leur confie certains rôles particuliers touchant le développement du territoire. La convention prévoit aussi le versement d'indemnités.

Le mode de vie

L'aménagement du complexe a grandement accéléré l'évolution de la société autochtone d'une part en offrant aux habitants des emplois salariés et en accentuant le contact avec des valeurs nouvelles et des produits venus du Sud et, d'autre part, en favorisant un certain maintien du mode de vie traditionnel et en permettant aux autochtones de gérer eux-mêmes leurs activités et services.

Les pratiques d'embauche de travailleurs autochtones ont développé le secteur du travail salarié. Ainsi, les entrepreneurs d'Hydro-Québec ont embauché quelques centaines de travailleurs chaque année pendant la phase de construction, pour le déboisement, le nettoyage et le réaménagement des aires de travail, le reboisement, les fouilles archéologiques, etc. De plus, des entreprises autochtones ont vu le jour, comme Cri Construction, Air Inuit et Air Creebec, grâce au fonds de compensation prévu par la Convention et aux contrats accordés par la SEBJ. Ces entreprises sont devenues des agents économiques importants dans la région.

En revanche, le mode de vie traditionnel a été favorisé par deux facteurs: la volonté de maintenir ce mode de vie, par l'institution d'un régime de revenu garanti pour chasseurs, pêcheurs et piégeurs et l'ouverture, grâce à la construction de routes d'accès, de territoires qui étaient de moins en moins exploités par les autochtones. On considère aujourd'hui que l'un des impacts majeurs de l'aménagement de La Grande Rivière est d'avoir augmenté l'accessibilité de l'arrière-pays.

Le système politique

La réalisation du Complexe La Grande a eu deux grandes conséquences sur l'organisation administrative des autochtones: elle a favorisé une certaine forme d'autogestion et entraîné la technocratisation de la société autochtone. L'administration locale et régionale est maintenant à 80 pourcent aux mains des autochtones et ceux-ci sont représentés dans tous les secteurs: éducation, santé, gestion des villages, etc. En revanche, les services sont de plus en plus équivalents à ceux d'une société industrialisée moderne, avec pour conséquence une infrastructure de plus en plus bureaucratique.

Une procédure particulière d'évaluation et d'examen des impacts sur l'environnement et le milieu social donne aux autochtones un droit de regard et d'examen sur la mise en valeur des ressources dans tout le territoire. Par elle, tout projet d'envergure est obligatoirement scruté pour qu'en soient minimisées les répercussions négatives sur les sociétés autochtones et l'environnement. La surveillance de l'application du régime est confiée à un Comité consultatif tripartite (Autochtone-Canada-Québec) dont le rôle principal est d'agir comme conseiller des gouvernements et des administrations ayant des pouvoirs réglementaires dans le domaine environnemental.

Le déplacement de populations

Fort-George, situé à l'origine à l'embouchure de la Grande Rivière, devait être protégé contre l'érosion des rives résultant de l'augmentation du débit de la rivière. De plus, pour obtenir un meilleur accès au réseau routier et améliorer les conditions d'hébergement, il a été décidé par les autochtones de déplacer leur village au nouveau site, qui porte maintenant le nom de Chissasibi. À la suite d'une planification très détaillée, des critères ont été établis pour l'aménagement du nouveau village et des prévisions ont été formulées. C'est ainsi que 40 millions de dollars ont été versés pour le relogement de la communauté crie de Chissasibi. Après coup, la satisfaction des habitants a été évaluée en fonction des différents critères. Le suivi montre un degré de satisfaction s'élevant à près de 70 pour cent.

4 Les Impacts Majeurs et les Mesures de Mitigation

Au Complexe La Grande, la création de cinq grands réservoirs et le détournement des eaux d'importantes rivières ne pouvaient se faire sans causer des répercussions considérables sur l'environnement. Dès le début du projet, l'équipe d'environnement, secondée par de nombreux spécialistes et des chercheurs universitaires, a conçu et mis en oeuvre des mesures de mitigation ayant pour objectifs principaux:

- d'assurer la qualité biologique et la productivité du milieu;
- de permettre l'utilisation des réservoirs pour la pratique des activités traditionnelles et récréatives;
- d'obtenir un milieu visuellement acceptable à proximité des sites fréquentés.

C'est ainsi qu'au complexe La Grande, pour faire des nouveaux milieux aquatiques des systèmes biologiquement productifs et intégrés dans un nouveau et harmonieux schéma d'utilisation du territoire, on a investi près de 3 pour cent du coût total du projet, soit 250 millions de dollars dont 65 pour cent ont été dépensés pour des mesures de mitigation et 35 pour cent dans des initiatives de connaissance du milieu et de mise en valeur.

Les réservoirs

L'inondation des systèmes terrestres, le rehaussement du niveau des systèmes aquatiques, les fortes variations annuelles du niveau des eaux, tels sont les impacts physiques les plus apparents de la création d'un réservoir.

De plus, avec la submersion des systèmes terrestres, disparaissent le couvert forestier et les habitats riverains qui constituent des milieux privilégiés d'alimentation, d'abris, de sites de reproduction pour de nombreuses espèces parmi la faune terrestre et la sauvagine.

Le rehaussement du niveau des eaux, pour sa part, détruit les sites de fraie pour l'ichtyofaune ou, du moins, crée des conditions hydrologiques et thermiques qui réduisent leur utilisation.

A long terme toutefois, si le patron de fluctuations annuelles et interannuelles de niveau d'un réservoir s'apparentait à celui des lacs naturels, un nouvel habitat riverain s'installerait et de nouveaux sites favorables au frai se reconstitueraient. Toutefois, tel n'est pas le cas et la bordure des réservoirs constitue dans l'ensemble un milieu pauvre et peu utilisé par la faune. De plus, certains poissons doivent migrer vers les tributaires pour assurer leur reproduction.

L'instabilité des berges provoquée par les fluctuations du plan d'eau et une attaque par les vagues à des niveaux toujours variables, amplifient encore davantage ces phénomènes. Cette réduction de productivité du milieu terrestre a, de ce fait, des répercussions négatives sur les populations locales dont les activités socio-économiques sont fortement associées à l'utilisation des ressources fauniques du milieu.

Pour pallier ces répercussions, un important programme de travaux d'aménagements écologiques a été réalisé par:

- des travaux de déboisement et de récupération des débris en vue de sécuriser la navigation et l'utilisation des portions facilement accessibles des nouveaux plans d'eau, de dégager l'embouchure de tributaires favorables au frai des poissons;
- la création de frayères sur certaines portions de berges de réservoir et la construction de passes migratoires;
- la remise en végétation des berges pour contrer l'érosion et reconstituer des habitats fauniques riverains.

Enfin, des manuels d'exploitation ont été élaborés dans le but d'édicter des consignes et des directives précises de protection de l'environnement quant à l'exploitation des ouvrages (évacuateurs de crues, ouvrages de contrôle, réservoirs, etc.) à la surveillance et à l'entretien des mesures de mitigation mises en place.

Zones à débit augmenté

Dans les zones à débit augmenté, où se produisent également des phénomènes de submersion, on trouve les mêmes types de répercussions que pour les réservoirs, mais cependant, en raison de la création de certains secteurs à écoulement très rapide, des phénomènes d'érosion et de transport de matériaux constituent des impacts supplémentaires.

Dans la zone du détournement Eastmain-Opinaca-Grande, l'un des secteurs les plus utilisés par les populations autochtones pour leurs activités traditionnelles, les mesures d'insertion comprennent non seulement la gamme prévue dans le cas d'un réservoir, mais aussi la mise en place de digues et d'épis de protection et l'excavation de chenaux qui ont permis de contrer les phénomènes d'érosion, de concentrer l'écoulement et de minimiser le rehaussement des plans d'eau et, par le fait même, de réduire les superficies inondées.

Zones à débit réduit

La réduction de débit en aval des sites de détournement engendre d'importantes baisses de niveau des eaux et, conséquemment, l'exondation des berges. Des mesures d'insertion visent soit à reconstituer les niveaux des plans d'eau, soit à stabiliser les berges exondées.

Dans les tronçons à débit réduit des rivières Eastmain et Opinaca, 4 biefs ont été protégés par la construction de seuils permettant de rehausser les niveaux d'eau à des côtes comparables à celles qui prévalaient dans les conditions naturelles. Plusieurs kilomètres de berge ont fait l'objet d'ensemencement et de plantations de végétaux pour contrer les phénomènes d'érosion.

Les mesures de mise en valeur

Il est bien évident que, malgré la réalisation de cet important programme de mesures de mitigation, certains impacts résiduels demeurent et c'est par l'intermédiaire de mesures de mise en valeur qu'ils peuvent être quelque peu atténués.

Une des ces mesures a été la création d'une société sans but lucratif qui avait pour objet d'atténuer les répercussions sur les activités de chasse, de pêche et de trappage des amérindiens cris.

Cette société (Société des travaux de correction du Complexe La Grande) est entièrement financée par le promoteur et gérée conjointement par le promoteur et la population crie. C'est un montant de 30 millions de dollars que lui a versé le promoteur et qu'elle a investi pour:

- le trappage intensif dans les réservoirs avant leur mise en eau et la relocalisation du castor;
- la réorganisation des terrains de trappage;
- des programmes destinés à augmenter l'efficacité de l'exploitation à des fins de subsistance;
- des programmes de formation pour les activités connexes à la chasse, à la pêche et au trappage;
- des travaux d'amélioration des habitats et d'augmentation de la productivité de l'environnement;
- un ensemble de travaux particuliers tant dans les communautés cries que sur l'ensemble du territoire touché par le Complexe La Grande.

De nombreux quais et rampes d'accès ont été aménagés, des sites de pêche intensive et des couloirs de navigation ont été préparés et les abords des ouvrages ont été complètement réaménagés avec la collaboration de la SEBJ.

5. Le Réseau de Surveillance Ecologique

Dans le but d'évaluer scientifiquement les changements qui surviendront dans le milieu lors de la création des réservoirs du Complexe La Grande, un vaste réseau de surveillance des conditions du milieu a été implanté.

Ce réseau était alors défini comme suit: l'implantation de stations de mesure des phénomènes biologiques et physico-chimiques permettant de suivre l'évolution temporelle de la qualité des écosystèmes aquatiques à l'intérieur du territoire des aménagements hydroélectriques de la Baie James.

Ce réseau fut par la suite agréé par un Comité consultatif d'experts de réputation nationale et internationale qui, de plus, a suivi jusqu'en 1982 l'évolution du programme de surveillance. Ce comité fut réduit à 5 membres jusqu'en 1985 lorsqu'il fut dissous. Les membres du comité furent choisis en fonction de leur champ particulier de compétence (physico-chimie, productivité primaire, zooplancton, benthos, poissons, etc.) ou de leur expérience plus globale au niveau de l'approche scientifique.

Les objectifs du réseau de surveillance écologique

Le réseau de surveillance entériné par le comité consultatif d'experts visait à rencontrer les objectifs suivants:

- *Evaluer*, par une approche scientifique, les changements physiques, chimiques et biologiques des réservoirs susceptibles d'affecter les ressources étroitement liées aux activités traditionnelles de la population résidente.

- Utiliser ces informations en vue de *rationaliser* les aménagements correcteurs (piscicoles, fauniques, stabilisation des berges) et la gestion des réservoirs.
- Profiter des connaissances acquises pour *améliorer* les méthodes de prédiction d'impacts et les mesures d'insertion lors de projets futurs.
- Suivre l'évolution des grands milieux aquatiques en territoire nordique afin de mieux comprendre les principaux mécanismes qui contrôlent les réponses de ces milieux dans le but de faire ressortir les éléments essentiels de futurs réseaux de surveillance dans un contexte géographique comparable.

Les structures du réseau

Le programme de surveillance écologique devait donc décrire et expliquer la nature et l'intensité des changements qui surviendraient lors de la création et pendant l'opération des réservoirs, de la coupure des rivières et de la dérivation des eaux vers d'autres bassins et ce, pour une durée de cinq ans à partir de la mise en eau.

Les mesures ont débuté de façon générale en 1977, 1978 ou 1980, soit deux ans avant la mise en eau des réservoirs et la modification des rivières, et se sont poursuivies annuellement jusqu'en 1984.

Dans chacun de ces réservoirs, on a placé des stations d'échantillonnage à l'entrée de tributaires importants, à la sortie des réservoirs et dans quelques milieux typiques. On a ajouté une ou deux stations à l'aval des ouvrages de contrôle, des centrales ou des évacuateurs de crues. Enfin, des stations en milieu non perturbé permettaient de déterminer si une variation est due à des agents naturels ou aux aménagements hydroélectriques. En se basant sur ces critères, on a créé 27 stations régulières d'échantillonnage.

Il a été jugé essentiel de suivre la qualité physico-chimique de l'eau et les répercussions sur les poissons, dont celle du mercure. Afin de mieux comprendre les mécanismes qui interagissent, des prélèvements sur la production primaire, le zooplancton et les organismes benthiques ont été effectués. Les fréquences et les méthodes de prélèvement sont présentées dans le tableau 5.

Dès 1986 et 1987, selon le cas, les campagnes de mesures se poursuivront tous les trois ans pour les paramètres physico-chimiques et tous les deux ans pour la teneur en mercure des poissons. Il en sera ainsi jusqu'à l'atteinte d'un état d'équilibre du milieu.

La banque de données écologiques

Après contrôle, les données ont été entrées dans une banque de données informatisées. A ce jour, la banque contient plus de 4 millions de données qui peuvent être extraites sous forme séquentielle ou groupées en tableaux.

Cette banque ne comprend aucun traitement statistique élaboré. Il est néanmoins possible de transférer le contenu de la banque, en tout ou en partie, à des firmes spécialisées pour effectuer les traitements statistiques qui sont nécessaires à notre analyse. Par ailleurs, nous rendons disponibles à la communauté universitaire ces données dont l'analyse peut faire l'objet de maîtrises scientifiques.

TABLEAU 5
PRINCIPALES ACTIVITÉS DU RÉSEAU DE SURVEILLANCE ÉCOLOGIQUE

DOMAINES	MÉTHODES	STATIONS	FRÉQUENCE 1977-1982	1983-1984
PHYSICO-CHEMIE SOMMAIRE	DIFFÉRENTES PROFONDEURS "HYDROLAB"	TOUTES LES STATIONS	2/MOIS EN ÉTÉ 4 FOIS EN HIVER	2/MOIS EN ÉTÉ 2 FOIS EN HIVER
PHYSICO-CHEMIE DÉTAILLÉE	ÉCHANTILLON INTÉGRÉ (0-10 m) ÉCHANTILLON DE FOND (1 m)	TOUTES LES STATIONS TOUTES LES STATIONS PROF.	2/MOIS EN ÉTÉ 4 FOIS EN HIVER 2/MOIS EN ÉTÉ 4 FOIS EN HIVER	2/MOIS EN ÉTÉ 1 FOIS EN HIVER 2/MOIS EN ÉTÉ 1 FOIS EN HIVER
PRODUCTION PRIMAIRE	ABSORPTION DU CARBONE RADIOACTIF	7 STATIONS	2/MOIS EN ÉTÉ	AUCUN EN 1983
ZOOPLANCTON	PRÉLÈVEMENT DE 0-25 m	TOUTES LES STATIONS	2/MOIS EN ÉTÉ	2/MOIS EN ÉTÉ
BENTHOS	SUBSTRATS ARTIFICIELS ET BENNES	TOUTES LES STATIONS	2/ANS EN ÉTÉ	ABANDONNÉ
POISSONS	2 SÉRIES DE 2 FILETS PENDANT 48 HEURES (24 HEURES EN 1983-1984)	TOUTES LES STATIONS	TOUS LES MOIS EN ÉTÉ	TOUS LES MOIS EN ÉTÉ
MERCURE	PRÉLÈVEMENT DE FILETS DES POISSONS	4 STATIONS EN 1978 2 STATIONS EN 1981 8 STATIONS EN 1982 12 STATIONS EN 1984	PENDANT L'ÉTÉ	PENDANT L'ÉTÉ

A ce jour, ces données permettent de conclure, entre autre, que l'apport d'éléments nutritifs lié à la submersion de matière organique lors de la création de réservoirs se traduit par une augmentation de la biomasse de poissons. La biomasse par unité de surface, quelques années après la mise en eau, est même plus forte que la biomasse des lacs les plus productifs de la région.

A plus long terme, on peut s'attendre à ce que la biomasse s'approche de celle des milieux environnants. Un des impacts sur la faune aquatique est une modification des espèces présentes. A cause de la perte des frayères, certaines espèces n'ont pu, dans les premières années, assurer le renouvellement des effectifs par la reproduction. Il en résulte une modification de l'importance relative de certaines espèces bien que la biomasse totale de poissons soit peu affectée.

Le mercure sur le territoire de la Baie James

Lors de l'élaboration du réseau de surveillance écologique, on avait greffé au programme de base l'étude des matières toxiques sur le Complexe La Grande.

Dès 1978, la SEBJ entreprenait une campagne de mesures pour établir les niveaux de référence en conditions naturelles des teneurs en mercure rencontrées dans les sédiments, l'eau et les poissons dans la région du Complexe La Grande.

Au total, les analyses de la teneur en mercure ont porté sur 3 679 poissons et la SEBJ complétait les informations en analysant 758 spécimens récoltés dans d'autres réservoirs québécois et leur milieu naturel adjacent.

Les résultats des campagnes de prélèvement avant la mise en eau démontrent que dans les milieux naturels, les teneurs en mercure des chairs de poissons non piscivores, comme le grand corégone et le meunier rouge, sont généralement inférieures à 0,2 mg kg⁻¹ sur l'ensemble du territoire de la Baie James, tandis que des concentrations supérieures à la norme canadienne de commercialisation qui est de 0,5 mg kg⁻¹ sont atteintes ou même dépassées pour des poissons de taille moyenne chez les piscivores tels le doré et le brand brochet.

Dans l'ensemble, les résultats, comme ceux présentés au tableau 6 pour le réservoir LG2, démontrent que les poissons des milieux modifiés ont connu de très fortes augmentations de leur teneur en mercure, allant du simple au quintuple et excédant plus souvent qu'ailleurs la norme fédérale de mise sur le marché.

Au Complexe La Grande, l'analyse des données les plus informatives recueillies par le réseau de surveillance écologique et dans les autres réservoirs du Canada, mène à un modèle conceptuel qui permet de croire que les non piscivores atteignent une teneur en mercure maximale cinq ans après la mise en eau du réservoir, tandis que chez les piscivores, les maxims seront vraisemblablement atteints en sept années. Des conditions naturelles devraient être retrouvées 10 à 15 ans après la mise en eau pour les espèces non piscivores et en 15 à 20 ans pour les espèces piscivores. Il apparaît donc peu probable que la situation qui prévaut actuellement hypothèque la survie des autochtones pour plusieurs générations à venir.

Le programme spécial mercure : La mise en eau du Complexe La Grande a privilégié l'habitat des poissons. Cependant, l'accumulation du mercure dans la chair des poissons des réservoirs représente un risque pour la consommation humaine et compromet

TABLEAU 6
 CONCENTRATIONS MOYENNES DE MERCURE DANS LES CHAIRS DES POISSONS
 DU RÉSERVOIR LA GRANDE 2

	ESPÈCE	ANNÉE	Hg (mg kg^{-1})	TAILLE CORRESPONDANTE (mm)
NON PISCIVORE	GRAND CORÉGONE	1978	0,13*	400
		1981	0,48**	400
		1982	0,52*	400
		1984	0,59*	400
	MEUNIER ROUGE	1978	0,12*	400
		1982	0,41*	400
		1984	0,66*	400
PISCIVORE	DORÉ	1978	0,80*	500
		1981	1,42*	500
		1982	2,21*	500
		1984	2,96*	500
	GRAND BROCHET	1978	0,48*	700
		1982	1,32*	700
		1984	2,66*	700

* D'APRÈS LES RÉGRESSIONS LINÉAIRES

** D'APRÈS LES MOYENNES PAR CLASSE DE LONGUEUR

momentanément l'exploitation des ressources fauniques, élément important de l'organisation sociale des communautés autochtones.

Afin d'être en mesure de participer à l'élaboration des moyens à mettre en oeuvre pour éliminer ou réduire les risques d'intoxication par le mercure des populations humaines, nous envisageons un programme de recherche sur le mercure dont les principaux volets sont les suivants:

- La poursuite du suivi de la teneur en mercure des poissons des réservoirs du Complexe La Grande et d'autres réservoirs d'Hydro-Québec afin de bien cerner l'évolution du phénomène;

- L'étude de la contamination des poissons de l'estuaire de la Grande Rivière et d'autres espèces de gibier (oiseaux, caribous et autres mammifères) composant l'alimentation des communautés cries;

- L'étude de l'importance de la pêche de subsistance et des habitudes alimentaires afin d'être en mesure de proposer des alternatives à la capture de poissons qui, même après plusieurs années de vie en réservoir, présentent des taux de mercure à peine plus élevés que la norme canadienne de commercialisation. A noter qu'aux Etats-Unis, la norme est de 1,0 mg kg⁻¹ au lieu de 0,5 au Canada;

- La participation aux études médicales des communautés cries en regard du problème du mercure;

- Une étude de faisabilité de traitements préventifs et correctifs visant à réduire la libération du mercure dans l'environnement, son accumulation par les poissons et sa toxicité pour l'homme.

Il faut dire ici que la pêche en réservoir est un phénomène nouveau qui n'appartient pas au mode traditionnel de vie des autochtones et que nous en connaissons mal son importance. De plus, connaître l'importance des espèces de poissons consommés est primordiale pour renchérir par exemple la consommation d'espèces, comme le corégone.

Un comité restreint mettant en présence des représentants des Cris et d'Hydro-Québec devra préciser les orientations de ce programme et proposer des solutions adéquates.

Conclusions

En matière d'implication environnementale dans un projet, nombreux sont les enseignements issus de l'expérience acquise au Complexe La Grande qui peuvent avantageusement être mis à profit dans la planification, la réalisation et l'exploitation de futurs projets de développement.

Cependant, il ne fait nul doute que, quel que soit le projet envisagé, la véritable garantie pour la protection de l'environnement tient à la volonté clairement et fermement exprimée par le promoteur d'en faire une partie intégrante de son processus de décision.

Aussi, dès le début du projet, les signes les plus importants augurant de la qualité environnementale de ce projet sont les suivants:

L'inscription, dans le cahier des charges du promoteur, des objectifs qu'il poursuit en matière de protection de l'environnement ainsi que des mécanismes qu'il entend mettre en oeuvre pour les atteindre;

l'existence ou la formation, dans l'entreprise, d'un groupe de spécialistes responsables des aspects environnementaux du projet et ayant droit au chapitre dans le processus décisionnel;

l'attribution d'un budget spécifique et bien défini à la réalisation des études et des travaux d'environnement.

La leçon de l'expérience en matière d'environnement au Complexe La Grande ne s'arrête cependant pas à ces considérations. En effet, au Complexe La Grande, il s'est révélé extrêmement positif de confier au groupe d'Environnement un rôle interne dynamique en lui permettant de s'immiscer quotidiennement dans les domaines de l'ingénierie, de la construction et de l'exploitation, alors que la plupart des équipes d'Environnement ont un rôle externe statique limité à la définition des impacts et à l'identification des travaux correcteurs avant l'autorisation de construire.

Cette attitude a donné lieu à l'élaboration et à la mise au point de tout un ensemble d'outils et de mécanismes originaux et adaptés à la nature du projet et au milieu touché.

La sensibilisation du personnel à tous les niveaux à la protection et à la mise en valeur de l'environnement s'est également avérée l'une des tâches les plus essentielles du groupe d'Environnement. A cet effet, le comité des experts, le Comité Environnement-Ingénierie, l'équipe permanente de protection de l'environnement au chantier, les directives d'environnement, le manuel d'exploitation des ouvrages et l'utilisation d'outils, tels que journées d'information, articles dans l'organe d'information interne, ainsi que les brochures, ont représenté les meilleurs médias pour rejoindre tour à tour les administrateurs, les concepteurs, les constructeurs et les exploitants et pour faire de la protection de l'environnement une réalité de tous les jours. Enfin, le maintien de liaisons efficaces et d'un dialogue constant auprès des populations locales a permis de maximiser les retombées régionales du projet et de le rendre socialement acceptable.

Le suivi environnemental a permis de vérifier, pendant la construction et l'exploitation des équipements, le bien-fondé des prévisions d'impact et des mesures de mitigation et de mise en valeur contenues dans les études d'avant-projet. Cette approche rétroactive permet une amélioration constante de la qualité des études. Le suivi est donc un instrument indispensable à toute démarche environnementale: il permet de saisir la nature véritable des impacts et des répercussions sur l'environnement; d'acquérir des connaissances qui s'appliquent à tout projet de développement; de réfléchir sur l'orientation à donner aux futures études d'avant-projets; et d'ajuster l'évaluation environnementale en fonction d'impacts non plus appréhendés mais observés.

Le Québec jouit d'un régime hydrographique extrêmement riche; près de 10 pourcent de sa superficie est recouverte d'eau douce. Ces rivières recèlent un potentiel hydroélectrique important.

Le potentiel restant économiquement exploitable est évalué à 15 000 MW dont 80 pourcent se situent au Nord du Québec. L'expérience de la Baie James et d'autres projets similaires a permis à Hydro-Québec de développer diverses stratégies qui sont consignées dans une politique d'environnement claire qui affirme sa responsabilité en matière de

protection de l'environnement et de mise en valeur de ressources affectées par ses activités. Cette attitude positive face à l'environnement, couplée avec une plus grande participation des divers publics concernés, permettra à Hydro-Québec de mettre en valeur de façon harmonieuse ce potentiel hydroélectrique.

PAPER 26

HYDROMETEOROLOGICAL VALIDITY OF LARGE-SCALE WATER PROJECTS IN THE USSR

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During recent years extensive experience has been gained in the USSR on the hydrometeorological validity of large-scale water projects intended for streamflow redistribution in time and space and for evaluations and forecasting of the results of the operation of these projects. The experience of other countries in this field has been generalized.

The main justification for water projects based on streamflow redistribution is an uneven natural distribution of water resources in space, great variations of streamflow within the year, long-term variations of annual streamflow, a disproportion between water demand and water availability intensified by the development of human activities, as well as the quantitative and qualitative deterioration of river water.

About 80 percent of total annual river runoff in the USSR (average about 3 900 Gm³) occurs in northern and eastern regions not sufficiently cultivated from the economic point of view, while less than 20 percent occurs in the southern economically highly developed and densely populated areas of the (south European USSR, Caucasus, Kazakhstan and Central Asia) (800 Gm³). According to available forecasts (Shiklomanov, 1979) the surface water resources in the arid zone of the USSR may be almost completely exhausted in the next 15 to 20 years. In addition to the general deficit, the southern areas are subject to periodic droughts which cause a great deal of damage to agriculture.

Another acute problem which justifies the urgency of space-time river runoff control is the necessity to maintain an optimum hydrobiological regime and fish productivity in the large water bodies of the southern USSR (Caspian Sea, Sea of Azov, Balkhash and Issyk-Kul Lakes), greatly dependent on the amount of inflow.

At present the runoff in the majority of the rivers intensively used for the national economy is under control. Total water storage in reservoirs is about 1 Tm³ (Anon., 1979). More than 60 Gm³ of river water are annually redistributed among river basins. The USSR holds the second place in the world as to the total volume of water redistributed after Canada where the annual volume of water transfers attains 140 Gm³. The Karakum Canal is the longest water management system. It is used to transfer up to 11 Gm³ of water annually from the Amydarya river to the south of Turkmenia over a distance of 1 100 km. Besides, 17 large canals were in operation in the USSR in 1985 transferring from 0.8 to 6 Gm³ annually over a distance of 100 to 460 km.

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The growth of the freshwater deficit in the southern areas led to the need to fund new methods ranging from strict water resources economy and various measures for maintaining satisfactory water quality and reducing non-productive water losses up to the discovery of additional sources of water, including the increase of river water transfers. For example, a system of hydraulic structures is projected in the basins of the Onega, Sukhona and Upper Volga basins to compensate 6 Gm³ of irretrievable annual water losses in the Volga basin caused by anthropogenic activity. The possibility and expediency of increasing the volume of water transfers from the northern rivers to the Volga by means of a diversion from the middle Pechora River, the Onega Lake, Lower and Sukhona and Northern Dvina is being studied. The problem of a large-scale water transfer from the Danube to the Dnieper and from the Lower Ob to Kazakhstan and Central Asia are also being considered.

Most water management systems in the USSR are multipurpose and include a great variety of hydraulic structures (reservoirs, pumping stations, canals, sluices, navigation locks, etc.) to guarantee the volume of water needed for irrigation, industrial and municipal water supply, power generation and navigation. Such multipurpose systems may be considered as individual fragments of the United Water Management System of the future to be used for the most effective water resources development for the combined hydropower and navigation systems of the country. Their effects on the environment may be substantial and may destroy the natural equilibrium in water and energy balances due to water division, areal redistribution of streamflow and a direct impact on the hydrological regime of the multipurpose structures of the system itself.

Hydrometeorological investigations, connected with large-scale water projects were designed to:

- define the necessity and scale of the project;
- select the optimal solution;
- develop measures to compensate the expected negative impacts;
- provide the project with all the required basic hydrometeorological data.

One of the most complicated and vital steps in the hydrometeorological studies is to predict possible results of construction and water project operation. Such studies are made in the USSR within the framework of a long-term multipurpose programme for a prospective water supply and water resources control for which the following main problems are to be solved:

- evaluation of present state of natural water resources;
- prediction of natural and anthropogenic changes in water resources, in water regimes of rivers, lakes and seas and future climatic changes;
- evaluation of ecological changes resulting from the projected water systems with an account of the predicted environmental changes.

The influence on the environment of large water management projects involving streamflow redistribution in time and space may be schematically presented as follows:

- (a) changes in the hydrological regime and quality of water bodies caused by a variety of hydraulic structures, water diversion and additional water discharges; creation of a new hydrographic network (canals for navigation and irrigation, "anti-rivers"); transformation of water ecosystems;
- (b) The effect of changes in the hydrographic network and irrigation on the regime, balance and quality of the groundwater of a river basin;
- (c) The effect of changes in the regime and quality of groundwater on the water and salt balance and on the energy balance of the basin, on the top cover and plants;
- (d) Changes in the hydrological regime of lakes and seas which receive water from the rivers in the basins in which the water systems operate;
- (e) The effect of changes in the basin and within lake and seawater areas on the meteorological conditions, on water circulation and on land ecosystems;
- (f) Different physiographic and ecologic changes caused by a complicated combination and long-term impact of direct and inverse cause-and effect relations.

Thus, a change in runoff volume and in the hydrological regime is the first link in the chain of nature-ecology transformations resulting from areal redistribution of streamflow. Changes in the volume and regime of streamflow lead to a formation of a new water-level regime, to more intensive (or attenuating) erosion and ice events, these changes affect drainage conditions and groundwater regime and finally are displayed in the water and energy balance of fluvial areas, their climates and development of water and land ecosystems. Therefore, the hydrological prognostic estimates are the basis of all the other nature-ecology prognostic estimates and serve as an essential parameter for estimating the socio-economic validity of water transfer projects, their efficiency and expediency. In the USSR the forecasts of the results of the construction and operation of large-scale water management systems are the responsibility of numerous research institutions. The major portion of hydrometeorological prognostic estimates is provided by the institutions of the USSR State Committee for Hydrometeorology and Control of the Natural Environment under the scientific guidance of the State Hydrological Institute.

The scientific validation of large-scale water transfers should include a long-term forecast of all the hydrological cycle components and environmental conditions within the framework of which the water systems will be constructed and operate. This forecast should in general be multi-variant and based on different scenarios of water management development and of possible anthropogenic changes of the global climate. A practical realization of the essential multivariant computations may be implemented on the basis of mathematical modelling of the whole water management system or of its individual sections (rivers, lakes, canals, reservoirs, "anti-rivers") and the processes expected to occur in them (formation of liquid and solid discharge, currents, water quality, conditions of ice formation and ice melt, regime of floodplain inundations, backwater evolution, waterlogging and drying of the areas adjacent to rivers, river-bed deformations, etc.).

During recent years a number of mathematical models have been developed in the USSR intended for the study of general and specific problems of water management projects and large-scale water transfers in particular. Concurrently with mathematical modelling, energy and water balance methods and computation of unsteady water motion have been widely applied as well as methods of mathematical statistics, analogy and physical modelling;

much work has been done by different field teams. In fact, for the hydrometeorological substantiation of areal streamflow redistribution, including a great variety of problems from engineering computations to long-term forecasts and development of principles for water resources control over vast areas, all hydrometeorological methods of computation and forecast are used.

When projecting large-scale water transfer systems for operation beyond the 20th century the following questions should be answered: will these water systems still be required in 25-50 years or later? Will they still be needed in view of natural and anthropogenic changes in climate? In what conditions of water availability will these systems operate in the future?

The research results obtained by Soviet and foreign climatologists based on a semi-empirical theory of climate and water circulation, on the studies of past climates, and forecasts of organic fuel consumption (Anon., 1982) show that by the end of the 20th century and especially at the beginning of the 21st century it is possible to expect a significant warming in the Northern Hemisphere due to the increase of carbon dioxide content of the atmosphere and of some other gasses producing a "greenhouse" effect. This anthropogenic warming, when added to the predicted natural warming of the climate at the end of the 20th century should first result in some decrease of water availability, and then, as a result of the increase of evaporation from the ocean, the water availability will increase intensively. The mechanism of transition from the predicted air temperature and precipitation to streamflow is not universal. Depending on the latitude of the location, the distance from the ocean and topography, the water balance components of river basins during different months will be subject to various changes.

Considering an insufficient knowledge of the water circulation process and climate, as well as of regional interrelations between the components of the hydrological and climatological cycles, only preliminary prognostic estimates may be obtained concerning streamflow changes. For example, according to the computations made by the climatologists at the State Hydrological Institute (M.I. Budyko, O.A. Drozdov) for the rivers of the north and north-west of the European USSR, mean annual runoff at the beginning of the 21st century may be slightly less. Some decrease in river runoff is also expected in the rivers of the Asian USSR, in the taiga and steppe zones in particular. As to the more remote future (2050) the water availability will be subject to a great increase in northern areas of the USSR, in the European USSR in particular, while in the southern river basins the water availability may be even less than at present.

Thus, during the present century the anthropogenic changes in climate will probably be insignificant and may be neglected in the case of water projects. When the water resources situation after 2000 is predicted it is necessary to take into account possible climatic changes, especially the increase of the difference between water availabilities in the north and in the south of the USSR, including water resources depletion in the arid southern zones where water resources are already almost completely used. In view of this forecast, it may be concluded that in the future the need of water transfers from north to south will be even more acute.

If, according to present forecasts, the climatic factors after the 20th century lead to an increase of water availability and river runoff in the northern areas of the USSR, the influence of human activities - deforestation, water consumption for domestic and industrial needs and for agriculture, various agrotechnical measures, filling and operation of reservoirs - will result in quantitative and qualitative (in the absence of water treatment and sewage wastes isolation) depletion of water resources in rivers.

In connection with the development of large-scale water transfers in the USSR, assumptions were made concerning the hazardous effects of water transfers on the global climate and water cycle (Adamenka et al., 1982). The mechanism of the global effects of large-scale water transfers was explained by possible changes in the total circulation of the atmosphere as a result of:

- decrease in the ice cover of the Arctic seas due to decrease of fresh water inflow;
- intensive increase of evaporation from irrigated areas;
- effects of the transfer of huge water masses on the velocity of the Earth's rotation.

In the USSR much emphasis is given to investigating the effects of large-scale water projects on climate and water circulation. The results of these investigations show that some decrease of river-water discharge into the Barentz and Kara Seas may affect in the regimes of these seas in different ways. On the one hand, the decrease of fresh water inflow from the continent should slow down the water exchange between the Arctic Ocean and the Atlantic Ocean, reducing the warm ocean water inflow to the Arctic Ocean and contributing to a more extensive cover there. On the other hand, the decrease of fresh water inflow may stimulate water exchange throughout the depth and increase the salt content at the surface. This process may be physically explained by the existence of a temperature inversion in the upper layers of the Arctic Ocean because of the dependence of the gradients of sea water density on mineralization and temperature. Moreover, the dependence of water density gradient on mineralization is several times greater than on temperature. In other words, the change in the ice cover of the Arctic Ocean is controlled mainly by a vertical distribution of salinity, while the fresh river water hinders the rise of warmer but more mineralized water to the surface thus producing favourable conditions for freeze-up (Zakharov, 1981). In the present state of knowledge of the fresh-water balance and ice content in the Arctic seas there is no unanimous opinion as to which of the two above processes will be predominant.

It is quite obvious, that the melting of multi-annual arctic ice will substantially affect the climate in the Northern hemisphere. The role of water diversion from the rivers of the Arctic basin on the scale at which it is planned at present should be negligible, according to the opinions of USSR climatologists (Anon., 1980). This conclusion has resulted from multipurpose energy and mass exchange investigations of continental and sea waters and water vapour transfer in the atmosphere on the basis of long-term hydrometeorological and aerological data. To discover the possible effects of the decrease of freshwater inflow on the global water circulation and ice cover of the Arctic seas, various annual volumes of inflow decrease were examined, including volumes exceeding those of the project (up to 200-300 Gm³).

Prognostic assessments of water and energy balance in the southern areas suggest that the more intensive evaporation due to extension of irrigation with water from the northern rivers will not affect the global climate and water circulation substantially (Grigorieva et al., 1983). An expectation of global climate changes resulting from additional irrigation in arid regions was based on the hypothesis that the increase of evaporation and humidity in the lower atmosphere would intensify the vertical exchange of water between the aeration zone and the atmosphere, that it would disturb atmospheric stratification and stimulate additional precipitation, with a consequent increase in river runoff. Computations made (Anon., 1980) for a hypothetical volume of additional annual evaporation of 125 Gm³ within the European USSR and central Asian USSR have shown that a small portion of compensative runoff from

the atmosphere is possible. According to computations (assuming of the above volume of additional evaporation) the annual runoff compensation may be 1.4 Gm³ in the European USSR and 3.6 Gm³ in the Asian USSR.

An examination of the hazardous effects of areal redistribution of large water amounts on the moment and velocity of the Earth's rotation and, consequently, on the circulation in the atmosphere, (Batrakov, 1971) showed that the effects of water mass redistribution for the purpose of water management were much less than the effects caused by natural water mass circulation such as tidal effects, sea currents, seasonal variations of ice and snow cover, volumes of inland seas and lakes, etc.

Thus, it is possible to assume that the implementation of runoff control and water transfers planned in the USSR would not produce irreversible global changes. Long-term investigations, however, show that in some specific cases the local changes may be substantial. The nature of water transfers and river runoff control effects on the components of the environment may vary within wide limits. This will depend on the scale of the projects (water volume in particular), on the engineering solution, and on the physiography of the terrain. In other words, it is necessary to establish a chain of cause-effect relations and to examine the corresponding possible positive and negative effects for each specific water project.

Despite the great variety of observed and expected changes resulting from water transfers and river runoff control in the environment, the main changes may be divided into three groups typical of the areas of water diversion, transport and utilization.

Area of water diversion, including donor rivers (i.e. rivers from which some water is to be transferred) diverting structures and adjacent river basins as well as lake and sea recipients. The main changes of physiographic and ecologic conditions result in this case from annual runoff decreases and changes in the regime of streamflow and water levels in donor rivers. Positive results which can be expected from water diversion and runoff control are:

- prevention of disastrous floods;
- reduction of water surplus in the floodplains;
- improvement of drainage conditions in the marsh areas adjacent to rivers and decrease of waterlogging;
- reduction in the severity of ice-dam formation.

Among negative impacts are:

- deterioration of water quality;
- decrease of thermal discharge into sea;
- longer duration of ice cover on rivers;
- more intensive riverbed deformations;

- longer duration of events accompanied by oxygen deficit, formation of new zones with oxygen deficit;
- reduced fish productivity of rivers;
- lower productivity of floodplain meadows.

The projects developed in the USSR for water transfers and water resources control provide a decrease of mean annual runoff in donor rivers of the order of 10-50 percent. In dry years, however, in case of constant annual diversions the relative decrease of water availability may be greater. Besides, the discharge of many donor rivers is greatly affected by human activities even to-day; in future the anthropogenic load on the streamflow of these rivers will be greater. For example, total anthropogenic annual losses of water in the Ob basin by 2000 are expected to attain 25-30 Gm³ or 6-9 percent of the mean long-term undistributed discharge at the mouth.

Anthropogenic changes in the annual runoff of possible donor rivers in the north of the European USSR (the Onega, Sukhona and Pechora Rivers) are not significant and will not exceed 2-5 percent before the end of the 20th century. Deforestation in these basins results in more variable annual runoff and significant changes in water regime, however, will appear before the next century.

Thermal runoff decrease and changes in the hydraulic parameters of flow and in the ratio of main river discharges to tributary discharge due to human activities and water transfer would lead to earlier freeze-up and later ice break in donor rivers. The air temperature in spring would be a little lower.

Lower water levels at the time of spring snowmelt floods (associated with water diversions and runoff control) should modify the natural regime of floodplain submergence. It should be noted that the floodplains of the northern rivers are the principal agricultural lands and are the habitat of valuable fish species in which they gain weight and spend winter. The major portion of the rural population lives within the floodplain and adjacent areas. The Ob-Irtysh floodplain is unique as to its area and economic importance. The dependence of different water users on the regime of floodplain flooding differs. The increase of flood areas in spring is always desirable for fish populations, while submergence of floodplain meadows for too long a duration may reduce their productivity and hinder the exploration of deposits in the floodplain.

According to the results of research, the fall of water levels in the northern and Siberian rivers will not greatly affect waterlogging. It will only contribute to the drainage of narrow strips of low moors along the river and more favourable conditions will be created for reclamation. The structure and water-energy regime of peat bogs in watershed-divides, characterized by a sufficient independence, respond slightly to the increase of the draining capacity of rivers.

Area of water transport comprises rivers, canals, "anti-rivers", along which the water is conveyed to the users, as well as the adjacent areas. The main negative impacts here are the following: rise (or fall) of the groundwater table (depending on the relation between surface and groundwater) in the areas along the water transfer routes. There is a great risk that various water-borne diseases may accompany the transferred water. In the case of unlined canals, it is very important to determine the optimum morphometric and hydraulic parameters for a maximum possible prevention of riverbed deformation, ice dams and ice jam, and to ensure minimum water losses.

In the upper reaches of the Sukhona River the water transfers will reverse the flow, and here "anti-rivers" will be formed. Methodologically, the prediction of hydraulic parameters and trends in riverbed deformations in "anti-rivers" is very complex and still under development. It is feared that the great friction of the natural slope during water transfer may cause bedload scour which could deteriorate water quality substantially.

When rational engineering solutions and appropriate measures of environmental control are undertaken in the areas adjacent to the water transfer routes these should be improved socially, economically and ecologically, by providing recreation, water supply, navigation, irrigation, etc.

Areas of utilization of the transferred water. Irrigation is the principal use of the water transferred in southern arid and semi-arid regions of the USSR. It is natural to expect the most favourable results in the areas where water is of a vital importance: improvement of land productivity, development of a guaranteed high quality farming, improvement of climatic conditions, etc.

The effect on the micro-climate of irrigating vast areas of land will be displayed by the changes in evaporation regime and volumes of evaporated water. During the first years of irrigation a direct effect of additional evaporation from irrigated areas should be observed. Later this effect will be supplemented by the influence of the transformed geotopes adjusted to a new ratio of heat and moisture and conditions of groundwater drainage. The climatic effect of evaporation may vary according to the background changes in temperature and humidity of the air. For example, the development of irrigation based on the water transferred from the north will result in a temperature fall and air humidity rise greater in the deserts of the Central Asia than in Kazakhstan and the Lower Volga for the same irrigated areas. In West Siberia, because of naturally high water availability, the effect will be even less than in Kazakhstan and the Lower Volga. In the case of extensive irrigation in the southern deserts of Central Asia the mean daily air temperature may fall by 3-4°C on average during the vegetation period while the air humidity deficit may decrease by 10-15 mb (Meleshko et al., 1982). A slight decrease of heat resources on irrigated areas in the hot climates of the arid zone should not negatively affect crops, while in the north, in West Siberia for example, the fall of air temperature due to irrigation may retard crop development and affect yields.

The most important problems to be solved in irrigated areas are the prevention of salinization, waterlogging, soil erosion and the impossibility of crop rotation. This is closely connected with the rational use of the transferred water and the increase of irrigation systems efficiency, without which it is impossible to expect a long-term positive effect from additional water availability. The great reclamation potential of water transfers may be reduced significantly by underestimating the importance of the irrigation aptitude of soils, the possible destroying of aggregates in some soils, and irreversible soda salinization. This mainly concerns water reclamation development in the south of West Siberia.

The hydrometeorological validation of large water transfer and river runoff control projects also included a development of recommendations aimed at the prevention or moderation of the negative results of the operation of such systems. These recommendations are:

- improvement (or conservation) of water quality throughout the system;
- optimization of the volumes transferred and of the regime of exploitation of the systems;

- determination of limiting volumes of water diverted from donor rivers;
- examination of different compensatory measures.

The estimation of the limits of permissible changes in runoff regime is a key problem which has not yet been properly studied in connection with water transfer projects. The very first steps in this direction were aimed at the determination of optimum runoff hydrographs from the point of view of socio-economic aspects and environmental control. The principle used was to ensure a possible increase of river system productivity with minimum negative ecological impacts. It was assumed that the optimum runoff hydrograph should meet the following requirements:

- satisfaction of the demand of the principal branches of the economy;
- maintenance of the ecological conditions of the river;
- provision of the required water quality;
- maintenance of the recreational value of the river.

This approach required a careful study of hydro-biological peculiarities of rivers, lakes and reservoirs, and an estimation of their economic, biologic and recreational importance. An attempt was made (Fashchevsky, 1982) to classify the proposed donor rivers according to principal physiographic and ecologic factors: fish productivity, game and recreational activities, floodplain meadow productivity. Estimation of actual runoff exceedance compared with the optimum design runoff made it possible to determine the "excess" water at various gauging sites in the northern and Siberian rivers which could be used to cover the water deficit of other basins.

This approach has been applied for the extensive investigations related to an optimization of the operational regime of existing and projected hydro-electric power plants on the Svir, Onega, Sukhona, Pechora and Sheksna Rivers in the event of water transfers and runoff control measures being undertaken. When selecting the optimization criteria, the following principle was applied: maximum possible satisfaction of the needs of navigation and power generation with minimum area of flooding and channel dredging.

As a result of these investigations it was established that the constant volume and regime of water diversion specified in the project from year to year did not correspond to the actual capacity of donor rivers in certain years and did not suit the needs of users in the areas of projected water use. The intra-annual regime of water transfer is not always sufficiently validated.

When selecting a water transfer variant, it is very important to analyse the synchronism of streamflow variations in donor and recipient rivers. It is quite evident that the maximum effect of water management may be obtained in case of asynchronous streamflow variations, providing a water surplus in wet years in the north for compensating water deficits during dry years in southern arid regions.

A comparison of correlation coefficients of annual streamflow in various water transfer projects shows, for example, that annual runoff in the lower reaches of the Danube and the Dnieper is highly correlated and consequently, there is a high probability of coincidence of

dry and wet periods on these rivers. There is a good synchronism between runoff variations in donor rivers in the north of the European USSR and in the Upper Volga River. This synchronism is revealed best during dry years. The provision of water to the Volga basin in dry years requires additional regulating capacities. In terms of physiography and ecology, however, the construction of large reservoirs is quite unfavourable in the northern plains which have a water surplus.

The probability of dry years coincidence in the Lower Ob and in the Syrdarya and Amudarya basins is low. Correlation coefficients of mean annual runoff series of these rivers are close to zero. The computation of a matrix of probable coincidence of the years with discharge of different frequencies shows that there were only two cases of discharge coincidence in the Lower Ob and in the Syrdarya within the frequencies exceeding 95 percent in the 1000-year model series.

The problems of water resources development and water control in rivers and reservoirs in the areas of water transfers require further investigation based on a system and closely related to physiographic, ecologic, technical and socio-economic aspects of the problem of areal water redistribution and river runoff control.

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PAPER 27

WATER CONSUMPTION, WATER AVAILABILITY AND LARGE-SCALE WATER PROJECTS IN THE WORLD

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During the last 20 years numerous efforts have been made in many countries to estimate present and future water consumption in the world for different economic needs. The results obtained based on various existing data, methodologies and accepted prerequisites are hardly compatible; it is very difficult to evaluate the validity and reliability of these results, especially the forecasts for the future. Nevertheless, an attempt is made here to do so on the basis of results of total water consumption estimates of the world as a whole.

Fig. 1 shows the total water consumption dynamics of the world based on the data obtained by many specialists during the last 15 years. They estimate the present annual water consumption of the world to be within the range of 3 000 and 4 500 Gm³, increasing to between 5 000 and 10 000-11 000 Gm³ by the end of the century. Naturally, the accuracy of these estimates is uncertain. Most reliable and detailed data were obtained in 1974 at the State Hydrological Institute (SHI) in the USSR (total and irretrievable water consumption of each continents by country and according to use for the period 1900 to 2000 (Kalinin & Shiklomanov, 1974; World water resources, 1974; Shiklomanov, 1979)) and in 1980 at the US Geological Survey (The Global 2000 Report, 1980). These estimates were presumably made independently and it is therefore interesting to compare them. This comparison is shown in Fig. 2 where it may be seen that there is agreement between the SHI data and US Geological Survey data concerning the water consumption of different water users for the whole world in general and the total water consumption by continent. This comparison of data from the above publications is possible for only a few items since the USGS publication does not contain data on irretrievable water losses, on water losses by evaporation from reservoirs, or on the dynamics and trends in world water consumption in the past and in the future.

Estimates and forecasts made by the SHI in 1974 are confirmed by the actual data on water consumption and by the results of generalizations and investigations made after 1974. Nevertheless, these data prepared more than 10 years ago, need to be up-dated and compared with more detailed information obtained recently; this particularly concerns such continents as Africa and South America for which there were practically no reliable data at that time. At present the detailed data available on many countries and continents makes it possible to analyse the ratios between water consumption and water availability, not only for the continents as a whole, but also within the continents for various physiographic and economic zones including the variation in time.

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The water consumption of large areas of the world is determined according to the following three basic factors:

- level of economic development;
- size of population;
- physiographic properties of the area including climate.

To analyse the space-time variability of the water consumption of the world, large physiographic and economic areas were selected within each continent, characterized by more or less similar physiography characteristics, and level of economic development: 26 such areas were selected altogether, that is from 3 to 8 areas from each continent.

Individual estimates were obtained for each area of the total water consumption and irretrievable water losses for the needs of urban (municipal water supply) and rural populations (agricultural water supply), for industry (heat and power industry included), for irrigation, as well as the water losses due to the additional evaporation from the water surfaces of man-made lakes. All the estimates were made for different design levels from 1900 to 2000. In this way, it is possible to follow the dynamics of the world water consumption in time and space during the present century with some extrapolations beyond 2000.

To evaluate the water consumption of individual physiographic and economic areas use was made of the data on actual or computed water consumption at present available with different degrees of detail and reliability for many countries of all the continents. Much detailed and reliable data, covering periods of several dozen years, are available in international publications or in the publications of individual authors for the following countries: Argentina, Australia, Brazil, Canada, Chile, Cuba, Egypt, practically all countries of West Europe, Japan, Mexico, Mongolia, South Africa, Turkey, the USA, and the USSR. Forecasts for the years 1990-2000 are also available for all these countries.

In the event of inadequate data on water consumption of some large country or region, estimates were made by indirect methods, with the use of analogies (i.e. countries of similar physiographic characteristics and approximately the same level and type of economic development).

The water consumed by the population was estimated separately for urban and rural areas, using demographic data available in every country and forecasts of the total number of inhabitants in towns and rural areas, as well as the values of specific water consumption per capita for each country, or by analogy. In the case of past and future estimates, trends in the changes of water consumption by urban and rural populations and irretrievable water losses as a percentage of the total water consumption were taken into account.

The estimates of water consumption for irrigation are based on the data from irrigated areas, published by FAO between 1961 and 1981 for practically all countries of the world as well as on the data of specific water consumption for irrigation obtained for many countries and averaged for individual regions. An accurate account of water used on irrigated lands to a great extent determines the accuracy of water consumption in the world, especially on such continents as Africa, Asia and South America where irrigation accounts for 70 to 90 percent of the total water consumption. The major part of irrigated lands of the world were placed under cultivation during the present century. At the beginning of the XXth century irrigated

lands covered 40 Mha and by 1975 they occupied 220 Mha (FAO), an increase of 350 percent in 75 years. About 60 percent of all irrigated lands are located in 5 countries of the world: China, India, Pakistan, USA and USSR.

China occupies the first place as regards the area of irrigated land. According to FAO data prior to 1981, irrigated lands in China increased from 77 Mha to 85 Mha between 1963 and 1975 whereas post 1981 data indicates that irrigated areas in China increased from 41 Mha in 1970 and 45 Mha in 1981 or 40 to 42 Mha less than the earlier estimate. This explains why, according to FAO data, the total irrigated areas of the world are reduced by 42 Mha (or about 20 percent).

In China it is probable that before 1981 the areas of so-called "mass" or "sky" irrigation were taken into account; this was the result of the "great jump" in the 1950s when water for irrigation was diverted from numerous small ponds, basins, etc. originally intended for rainwater storage. When after 1981 only areas with regular irrigation systems and other engineering structures were taken into account, the irrigated areas appeared to be less than they had been before. The more recent data has been used in the present estimates.

As regards estimates prepared for the 1990-2000 horizon, the forecasts of irrigation development in different countries have been used; moreover, it was assumed that the specific water consumption has a decreasing trend because of the incidence of improved technologies, on-farm equipment and irrigation methods making for more economic use of water. The return flow has been assumed to be equal to 20-50 percent of the water diverted.

The industrial water consumption was computed on the basis of growth of industrial production in various regions of the world; the available data on the growth of this item of water consumption in countries with different levels of economic development and situated in various physiographic zones were used to define analogies. Computations were made individually for the thermal power industry and for other branches of industry with various trends and rates of development and irretrievable losses, and the results were summated for each region. Consumptive losses for the thermal power industry were assumed to be in the range of 1 to 4 percent; for other branches of industry from 10 to 40 percent, depending on the level of industrial development, the availability of systems for recovering return flow and on climatic conditions. It was assumed that the future industrial production and consequently the water consumption of the developing countries will increase at a much higher rate than in the developed countries.

Additional water losses due to evaporation from reservoirs were computed for all the reservoirs of the world with volumes exceeding 5 Gm³, using the difference between mean evaporation from water surfaces and from land; a coefficient based on the ratio of additional area of reservoir water surface to its total area was used.

The total water losses due to evaporation for each region was computed by summing up the data of all large reservoirs (more than 5 Gm³) and increasing the result by 20 percent because reservoirs with volumes exceeding 5 Gm³ represent only about 80 percent of the total volume and water surface areas of all the reservoirs of the world.

Future evaporation losses from reservoirs in each region were computed according to trends in the rates of planning and construction of large reservoirs in various countries and regions, and their particular physiographic features.

Before analysing the water consumption of the different regions and continents it is interesting to consider the trends of water consumption in the two largest countries of the world - the USA and in the USSR - which represent the major portion of industrial production and for which detailed investigations are available. Moreover, the trends observed in the USA and USSR concerning water consumption are typical of those of many other developed countries.

In the USA a detailed evaluation and long-range forecasts (2000-2020 horizon) of water consumption for various needs were first made in the 1960s' and published in 1965 (Landsberg et al., 1965) and again in 1968, on the basis of the results of the first national water resources assessment (White, 1973). The main conclusions drawn from these assessments and forecasts during 1965-1973 are widely published and are well-known to the specialists concerned. In particular, an analysis of this data in the form of water consumption trends in the USA for 1900-2000 is given in an SHI publication (Kalinin & Shiklomanov, 1974); data on the total and industrial water consumption in the USA for that period are shown in Fig. 3a. According to the forecasts made at that time for the years 1970-2000, the fresh-water consumption in the USA was expected to increase by between 100 and 150 percent annually (850 to 1 100 Gm³). Moreover, the major portion of that increase was attributed to municipal, industrial and thermal power uses. Since 1975 in the USA there has been a fundamental change in the approach to water resources development, with more emphasis given to the problems of saving water resources, re-use of water, widespread use of salt or sea water and a transition from extensive to intensive and multipurpose water resources development. This has led to a certain stabilization of water consumption and has given rise to a fundamental revision of water consumption forecasts. Forecasts made during the period 1975-1979 assumed a substantial decrease in the water consumption between 1980 and the end of the century (Timashev, 1983; Elniper & Vasiliev, 1983) (Fig.3a). It was assumed, in particular, that the total annual water consumption in the USA by 2000 would decrease (if compared with 1970) approximately by 80-90 Gm³ (15-20 percent) with respect to 1970. This will result mainly from a decrease of fresh water consumed by industry and thermal power generation. New trends in water consumption in the USA and forecasts for the future are widely discussed in the press, but the published data on actual water consumption indicate a less optimistic situation however.

In 1983 the US Geological Survey (National Water Summary, 1983) made a detailed analysis of trends in the actual water consumption for various needs throughout the USA during the period 1950-1980; these are the most reliable and most recent data of actual water consumption in the USA (Fig. 3a). They show that during 1950-1980 an increase in water consumption occurred in all branches, including industry and thermal power generation, though the rate of growth decreased substantially after 1970. Thus, the significant decrease in US water consumption predicted in the 1970s' had not occurred by 1980; during the period 1970-1980 the total fresh water consumption increased by 15 percent and irretrievable water losses by 17 percent. Taking into account actual data and the trends in water consumption during the years 1950-1980 as well as forecasts for 2000 (Timashev, 1983; Elniper & Vasiliev, 1983; National Water Summary, 1983; Water economy prospects for 1990 and 2000), a more precise forecast of the US water consumption before the end of the century may be characterized by the values shown in Fig. 3a.

Similar trends in water consumption and forecasts for the future are observed in the USSR. During the 1960s' and 1970s' a great increase in water consumption was predicted up to the end of the century (see Fig. 3b); during the period 1970-2000 consumption was expected to increase by 600-700 Gm³ each year (Kalinin & Shiklomanov, 1974; Lvovich & Koronkevich, 1971). Recently, however, the long-range forecasts of water consumption in

the USSR have been revised substantially on the basis of more rational water resources development, wider application of water re-use in industry and thermal power generation, and the application of more efficient methods of irrigation (see Fig. 3b). The much greater increase in water consumption in the USSR compared to that of the USA in recent decades is explained by several factors: more intensive irrigation development (irrigated areas are expected to increase by 70 percent in the USSR by the end of the century, whilst in the USA this increase will amount to only 10 to 20 percent), by more intensive industrial production and thermal power generation, and also by the fact that salt or sea water has become of great importance in the USA as a water supply for the thermal power industry. In 1980 about one third of water supplied for thermal power generation was salt water and by the end of the century the portion of salt water supplied to this branch will be no less than 60 percent of the total.

Water consumption trends in the world are shown in Table 1 for individual continents. Up-to-date (1980) total annual water consumption in the world is 3 300 Gm³, irretrievable water losses are 1 950 Gm³ (59 percent of the total water consumption). By the end of the century it is possible to expect a total annual water consumption as high as 5 200 Gm³ (increase of about 60 percent) and in irretrievable water losses attaining 2 900 Gm³ (150 percent increase); about 60 percent of the total water consumption and about 70 percent of irretrievable water losses occur in Asia where the major portion of irrigated land is situated. The role of various human activities in the trends of total water consumption and irretrievable water losses in the world, as well as the increase of irrigated areas are shown in Table 2. At present 69 percent of the world's total water consumption and 89 percent of irretrievable water losses occur in agriculture; in the future the share of agriculture will be slightly less as the water consumption by industry increases. As to the total irretrievable water losses, the portion due to additional evaporation from reservoirs is significant, since it exceeds irretrievable water losses by industry and municipal needs taken together. According to revised data, the irrigated areas of the world in 1980 occupied 217 Mha; by the end of the century irrigated lands are expected to cover 347 Mha.

Data similar to that shown in Tables 1 and 2 have been obtained not only for each continent but also for all selected physiographic and economic areas.

The present and expected water consumptions of individual areas and continents were compared with the surface water resources represented by total annual river runoff. The total water consumption in the world for various economic needs was 7.5 percent of total river runoff in 1980, it is expected to increase to 11.6 percent by 2000. Values of the present and future water consumption in terms of total river runoff are not great in general. The distribution of water resources in the world is extremely uneven, however, as shown by comparison of the water consumption and river runoff of different continents. At present the water consumption in Europe and Asia exceeds 13 percent of the river runoff and in the near future it will attain 20-25 percent whereas only 0.9 percent of the river runoff is utilized in South America, and this value will hardly exceed 2 percent before the end of the century.

Still greater unequal river runoff distribution and water consumption is observed within continents; at the present time the total water consumption in many large areas of the world attains 20-65 percent of the total river runoff (North Africa, Central Asia and Kazakhstan, West and South Asia, Trans-Caucasus, USA, South and Central Europe, South European USSR); before the end of the century it is expected to rise to 40-100 percent which means that in some areas the river runoff will be entirely used up.

Table 1 Annual Water Consumption Trends in the World (Gm³)

Continents	Years						1980		1990	2000	
	1900	1940	1950	1960	1970	1975	Vol.	% of total		Vol.	% of total
Europe	37.5	70.9	93.8	185	294	358	435	13.1	554	673	13.0
	17.6	29.8	38.4	53.9	81.9	106	127	6.5	178	222	7.7
Asia	414	682	859	1 220	1 520	1 690	1 910	57.5	2 440	3 140	60.5
	323	524	654	932	1 120	1 250	1 380	70.8	1 660	2 020	69.7
Africa	41.8	49.2	56.2	86.2	116	153	168	5.1	232	317	6.1
	34.0	39.0	44.6	65.7	88.3	120	129	6.6	165	211	7.3
North America	69.4	221	286	411	556	602	663	20.0	724	796	15.3
	29.3	85.8	107	145	183	199	224	11.5	255	302	10.5
South America	15.1	27.7	59.4	63.5	85.2	98.2	111	3.4	150	216	4.2
	11.3	20.6	44.7	44.4	57.8	64.6	71.0	3.7	86.5	116	4.0
Australia & Oceania	1.6	6.8	10.4	17.4	23.3	26.7	29.4	0.9	37.6	46.8	0.9
	0.6	3.3	5.1	9.0	11.9	13.8	14.6	0.8	17.4	22.0	0.8
Total	579	1 060	1360	1 980	2 590	2 930	3 320		4 140	5 190	
	416	703	894	1 250	1 540	1 750	1 950		2 360	2 890	

The present average irretrievable water losses of the world and of the individual continents are not significant and vary from 0.6 percent (South America) to 9.6 percent (Asia) of the total river runoff; by 2000 these values are expected to increase by 50 percent. In some areas, however, within the continents the variability of these values is much greater and ranges from 0.07 percent to 50 percent to-day and will rise to between 0.18 percent and 75 percent by 2000.

As to large regions, for which the distribution of the continental water circulation may be of great importance, irretrievable water losses cannot be linked to the decrease of the total annual river runoff. In fact, even if it is assumed that irretrievable water losses in the region is entirely attributable to additional evaporation losses, then according to the general theory of water circulation, the latter will contribute to rainfall increase, and this may greatly compensate water losses resulting from the economic needs of some regions. This is illustrated in Table 3 which gives the results of approximate computations of additional

Table 2: Trends of Annual Water Consumption in the World according to Use (Gm3)

Water User	Years						1980		1990	2000	
	1900	1940	1950	1960	1970	1975	Vol.	% of total	Vol.	Vol.	% of total
Irrigated lands (Mha)	47.3	75.8	101	142	173	192	217		272	347	
Agriculture	525	893	1 130	1 550	1850	2 050	2 290	68.9	2 680	3 250	
	409	679	859	1 180	1 400	1 570	1 730	88.7	2 050	2 500	86.2
Industry	37.2	124	178	330	540	612	710	21.4	973/	1 280	24.7
	3.5	9.7	14.5	24.9	38.0	47.2	61.9	311	88.5	117	4.0
Municipal Needs	16.1	36.3	52.0	82.0	130	161	200	6.1	300	441	8.5
	4.0	9.0	14	20.3	29.2	34.3	41.1	2.1	52.4	64.5	2.2
Reservoirs	0.3	3.7	6.5	23.0	66.0	103	120	3.6	170	220	4.2
	0.3	3.7	6.5	23.0	66.0	103	120	6.1	170	220	7.6
Total	579	1 060	1 370	1 990	2 590	2 930	3 320	100	4 120	5 190	100
	417	701	894	1 250	1 530	1 750	1 950	100	2 360	2 900	100

Note: The upper values indicate the total water consumption and the lower indicate the irretrievable water losses.

precipitation and discharge for individual continents resulting from future irretrievable water losses for economic needs. The computations were made according to the method of O.A. Drozdov (Drozdov, 1972) individually for every region and then averaged for whole continents. According to the data in Table 3, irretrievable losses for economic needs will result in a total precipitation increase in Europe, Asia and North America of 65-116 percent of the appropriate values of consumptive use by 2000. In the same way runoff will increase by 17-34 percent of the total irretrievable water losses.

The uneven distribution of water resources over the world and its divergence in terms of population location and economic development may be presented visually by comparing the specific water availability per capita in individual regions over identical time periods. The regional per capita water availability was determined by dividing the total annual regional river runoff (minus irretrievable water losses) by the population for each region and continent for 1950, 1960, 1970, 1980 and 2000.

The analysis of the data shows that in 1950 most regions were characterized by average annual water availability (5 100-10 000 m³ per capita), above average (10 100-20 000 m³ per capita) or very high (more than 20 100 m³ per capita); low values were found only in North Africa, Central and South Europe, China and South Asia (2 100-5 000 m³ per capita); no regions in the world were found to have very low water availability (1 100-2 000 m³) or extremely low (less than 1 000 m³). In the last 30 years the water availability greatly decreased in many regions of the world; it is extremely low in North Africa, very low in the north of China and Mongolia, Central Asia and Kazakhstan and it is low in 6 other regions of the world. By the end of the century extremely low water availability is expected in 8 of the 26 regions selected (North Africa, Central Asia and Kazakhstan), very low in 3 areas (North China and Mongolia; South and West Asia), low in 7 areas (Central and South Europe; south of the European USSR, South-Eastern Asia, Western, Eastern and Southern Africa). Concurrently, a very high water availability is observed in Northern Europe, in the north of European USSR, in Canada and Alaska, almost all over South America, in Central Africa, in Siberia and the Far East, in Oceania. It should be noted that the trends of water consumption are as follows: the rate of decrease is most substantial in the areas with low water availability, where water deficits are observed. For instance, in areas of least water availability (Central Asia and Kazakhstan, North Africa) it is expected to decrease by a factor of 11 during the period 1950-2000, while in the areas with sufficient water availability (Siberia and Far East, North Europe, Canada and Alaska, Central Africa) by a factor of only 1.5 to 5 during the same period.

Thus, the existing natural uneven distribution of water resources is subject to still greater unevenness where the demand of high due to human activity. In this connection a scientific approach and the development of effective measures to eliminate freshwater deficits in certain regions is of the utmost urgency.

It should be noted that forecasts of future water consumption are based on the assumption that the climate will not change, that available water resources are typical of mean climate conditions of every region and that possible future anthropogenic changes in the global climate are not taken into account. This assumption is based on the fact that, as suggested by climatologists, the anthropogenic changes in climate before the end of the century, including those caused by increased C² O concentration in the atmosphere, will be insignificant and will not greatly affect freshwater resources and their development. To predict water resources changes in river basins, regions and continents beyond the years 2010-2020, it is essential to take into account possible anthropogenic climate changes.

At present and in the foreseeable future, large-scale water projects aimed at the elimination of freshwater deficits in the world seem to be feasible if the following actions are undertaken:

- extensive saving of water by a very significant decrease of specific water consumption, especially in irrigation and industry;
- more complete use of local water by the introduction of seasonal and long-term streamflow regulation;
- utilization of saline and brackish water;
- artificially induced rainfall;

Table 3: Changes of annual precipitation and river runoff from the continents due to water consumption in 2000 (Gm3)

Continent	Mean annual runoff of rivers	Irretrievable water losses for economic needs, U_{ec}	Total additional precipitation, ΔP	Volume of additional discharge, ΔQ	$\frac{\Delta P}{U_{ec}} \cdot 100\%$	$\frac{\Delta Q}{U_{ec}} \cdot 100\%$
Europe	3 210	222	173	55	77.9	24.8
Asia	14 410	2020	1 320	512	65.3	25.3
Africa	4 570	211	245	36	116	17.1
South America	11 760	116	0	0	0	0
North America	8 200	302	338	104	112	34.4
Australia & Oceania		2 390	22	0	0	0

- utilization of secular storage of water in lakes, glaciers and snow including Antarctic icebergs;

- areal redistribution of water resources.

When all these measures are examined it can be seen that they call for considerable investments and that many are subject to certain environmental restrictions. Waste-water treatment and reduction of specific water consumption are an exception since such measures are always desirable and useful for the conservation of water resources and the environment.

Among the ways of eliminating water deficits the most attractive would appear to be: induced precipitation, runoff regulation by reservoirs and use of glaciers in mountain areas. Streamflow regulation makes it possible to use the local river runoff more completely but there is a decrease of the total water resources of the area due to additional evaporation. The negative ecological consequences are quite significant, especially when large reservoirs are constructed in the plains. As to artificially induced precipitation and the utilization of glaciers, the analysis of up-to-date publications shows that the possibilities are very limited both with respect to the amounts of additional water and as regards to the areas where these measures may be implemented. The ecological consequences of such measures are fairly

significant and difficult to predict. In view of this these measures should not be considered as real sources of additional water resources in the near future for the satisfaction of water supply needs on a global scale.

As to other ways of obtaining additional water, such as desalinization of saline and brackish water, the utilization of the glaciers of Antarctica and areal water resources redistribution, these may, depending on their specific costs and possible scales of application in the future, be capable of solving the water supply deficit on a global scale. It is natural that all these measures will sooner or later be widely resorted to in those areas where they will be most applicable and profitable, according to physiographic conditions and the type of water use.

For example, the cost of 1 Mm³ of fresh water obtained at modern desalinization installations ranges from US\$ 100 to 1 600 depending on the method, the capacity of the installations and the dissolved solids content of the treated water. The incidence of desalinization in the world tends to grow rapidly, but not as rapidly as was predicted 20-25 years ago. For instance, the total annual capacity of desalinization installations in 1960 was 80-90 Mm³, in 1970 it was 340-450 Mm³, in 1977 1 400 Mm³ of fresh water was produced. According to approximate estimates at the beginning of the 1980s' the annual volume attains about 3 000 Mm³. It is possible to assume that by the end of the century the total annual production of fresh water from saline and brackish water will hardly exceed 35-55 Gm³. It may be noted that in the 1960s' the forecasts for water desalinization were more optimistic; it was assumed, for instance, that 50 Gm³ of fresh water would be obtained annually by 1990.

Desalinization of water on a large scale raises complicated problems of salt utilization and treatment; this to a great extent determines the cost of the treated water and the impact on the environment for which no effective solution exists as yet.

According to estimates, the cost of fresh water obtained by transporting icebergs from Antarctica to arid zones (with the account of delivery costs to the user) is of the order of US\$ 0.5 to 0.7 per m³. If such projects are envisaged, none have so far been put into practice. The scale of future projects will depend on the results of initial tests. By the end of the century it is expected that the use of water from the icebergs of Antarctica will amount to several dozens of cubic kilometres per year. Large-scale use of icebergs would call for the solution of not only economic and technical problems, but also of some important ecological and political problems. The use of icebergs from Antarctica is one way to ensure interzonal redistribution of water resources over large distances involving consequences on the environment in the areas of water removal, transportation and utilization.

Areal redistribution of streamflow is widespread at present all over the world and perspectives for further development are promising. Inter-basin transfers are largely dependent upon the abundance of water, its areal distribution and the nature of water resources development. The total amount of fresh water available on the Earth in terms of annually recoverable streamflow is quite sufficient to satisfy the water needs for many dozens of years. The fresh water resources of the Earth are however distributed extremely unevenly, hence there are regions on every continent which have a water surplus whilst others have a water deficit. Moreover, human activities often result in an even greater disequilibrium in areal water distribution. In areas of water surplus the use of water is limited and river runoff is practically not reduced while in areas of water deficit human activities result in deficits which become more and more severe every year. It is therefore natural that man has developed measures to transfer water from areas with a water surplus to those with a water deficit. It is also natural that in the future, with the increase of water demand and the

development of technical facilities and economic possibilities, the number and scale of such projects will increase.

Depending on the volume of transfer, the route distance, the pumping lift and topographic considerations, the cost of transferring 100 Mm³ of water involves an investment of US\$ 100-800 M. Contrary to desalinization and the towing of Antarctic icebergs, basin transfers are in operation throughout the world in all physiographic zones, regions and continents. The total volume transferred is about two orders of magnitude more than the total volume desalinized and it is growing rapidly.

Table 4: Trends of water transfer volumes in various countries of the world (Gm³ year⁻¹)

Countries	1900	1920	1940	1960	1970	1980	1985	2000-2020 (projected)	
								min. total	max. total
Canada	7	7	10	14	25	90	140	260	300
USA	-	2	20	26	27	27	30	150	200
Mexico	-	-	-	1	4	4	9	10	15
USSR	-	-	8	10	25	47	60	100	200
Danube countries	-	-	-	-	-	2	(5)	15	20
India	15	15	18	18	22	37	50	130	300
China	-	-				(10)	30	40	
Other Countries*				40	45	50	60	65	80
Total (incomplete)	22	24	56	109	148	257	(364)	(760)	1 155

*Incomplete data. includes water transfers in Australia, Israel, Iran, Pakistan, Republic of S. Africa, Spain.

Basin transfers have existed for many centuries; with time they have become more complicated, often multipurpose, involving the transfer of larger flows over greater distances.

At present a great number of basin transfer systems are being designed, are under construction or in operation. They differ in capacity, in purpose, in structural components and geomorphology of the region. According to hydrographic criteria, it is possible to select from three types of water transfer system: local, intra-basin and inter-basin. According to the physical features of the area and the water use, water transfer systems are either intra-zonal and inter-zonal. In terms of complexity, their cost and their impact upon the environment, the most important characteristic is the scale of the project which is a product of the annual volume of water transferred and the distance travelled by the water. At the beginning of the century this product did not exceed $100 \text{ Gm}^3 \text{ km}$, whereas to-day it exceeds $12\,000 \text{ Gm}^3 \text{ km}$ (the largest water transfer system is the Karakum Canal in the USSR which transfers 11 Gm^3 annually over a distance of $1\,100 \text{ km}$), and by the end of the century the scale of annual world water transfers is expected to rise to $20\text{-}25 \text{ Tm}^3 \text{ km}$.

At present the total annual volume of water transfers in the world is about 400 Gm^3 , of which 140 Gm^3 are in Canada, 60 Gm^3 in the USSR, 50 Gm^3 in India and 30 Gm^3 in the USA. More than one hundred large-scale water transfer systems are in operation or under construction in many countries of the world. By the years 2000-2020 the annual volume of water transfers in the world is expected to reach $800\text{-}1\,200 \text{ Gm}^3$ (Table 4).

The importance and complexity of the problems encountered by large-scale water transfers are not so much due to technical features as by their impact upon the environment, even in the most remote regions of the hydrographic network. The importance of environmental impact investigations and forecasts will increase with the scale of water transfers as is always the case when human activities expand. At present, whenever large-scale water transfers are planned or implemented, the most important problem is to evaluate their effect on the environment and to make extensive forecasts of possible ecological results.

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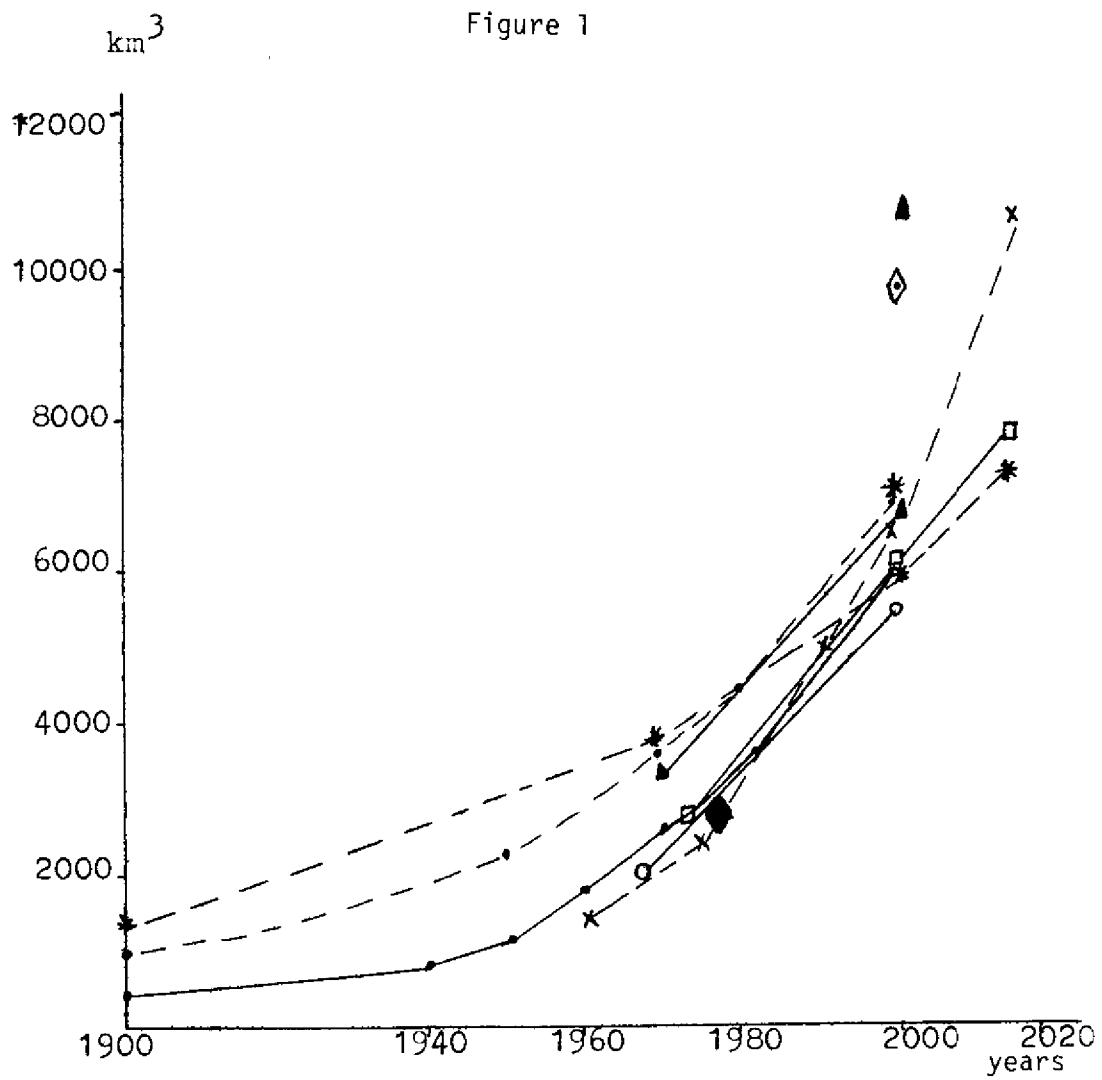
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Figure 1



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PAPER 28

ENVIRONMENTAL IMPACTS OF LARGE WATER PROJECTS IN CHINA

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Since the foundation of the People's Republic, China has made great achievements in water conservancy works, including 86 880 reservoirs, 6.4 million storage ponds with total storage capacity of 410 Gm³, 2 193 MW of hydropower installations, 160 000 km of dykes and 100 000 km of river channels and waterways improved for navigation.

As water projects, especially the large ones, can affect the physical, biological and human subsystems in many different ways, their effects may be either beneficial or adverse. Hence water projects may be called ecological projects in this context.

Since the 1970s, quite a number of environmental studies and assessments have been made for existing projects, and projects under construction or planning, such as the Sanmenxia Reservoir on the Yellow River, Xinanjiang Reservoir on the Zhigiang River, the Gezhouba and Three-Gorges project on the Yangtze River, the Danjiangkou project on the Han River and the South-to-North water transfer project, etc. Based upon the experience gained, documents have been drawn up, such as "Several rules" in 1982 and "Draft regulations" in 1985 for the formulation of Environmental Impact Assessment of water projects.

An analysis of different types of large water resource projects shows for instance that inter-basin water transfers have an environmental impact and bring about ecological changes in the exporting region, in the water transfer region and in the water importing region. Based on Chinese practice, including several such projects already in operation such as the Luan He-Tianjin and Biliu He-Dalian water transfer projects, as well as quite a number of projects under planning, the largest of which are the South-to-North project (East Route and Middle Route) and the Yellow River-Qingdao project. The principal environmental problems may be summarized as follows:

1. Exporting region

- Fall of water levels in the navigation channel downstream of the diversion;
- Sea-water intrusion in the river estuary;

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- Coastal ecosystem changes;
 - Hydrological regime and climate impacts;
2. Transfer region
- Groundwater level changes;
 - Drainage system;
 - Aquatic ecosystem modifications of associated lakes and reservoirs;
 - Propagation of water-borne diseases;
3. Importing region
- Salinization of soils;
 - Groundwater regime changes;
 - Hydrological regime and climate modifications;

There are also impacts on water quality, flora and fauna, together with economic and social effects in the exporting, transfer and importing regions.

Unlike the inter-basin water transfer projects of some other countries, China's water exporting, transfer and importing regions are almost always in the densely populated industrial and agricultural areas and great attention must be given to environmental impact assessments. Moreover, before the foundation of the Republic, schistosomiasis was endemic in large areas of the Yangtze River basin, eleven of the 30 provinces of China being affected. It was not only a local problem but also a major threat to social and economic development at the national level. So it is of deep concern in the case of the South-to-North water transfer project to determine whether schistosomiasis could migrate northward with the transferred water. The key lies in whether the host snails will travel north with the water. According to research and observations on the subsistence and breeding of host snails, carried out at experimental sites of the northern region where snails were not present in the past, it was proved that by virtue of the unfavourable soil conditions and low atmospheric and soil temperatures, that the northern limit of snail habitats is Baoying County, Jiangsu Province (33°15'N).

In view of the complexity of the project an attempt has been made to apply information theory and systems approach to coordinate the water and related land resources development with the environmental problems. Such a large scale system can form patterns of entropy flow and information flow. By the entropy change analysis, some environmental problems can be treated as entropy production (increase of the degree of disorder), while the result of the environmental protection and natural resources conservation can be measured by entropy reduction or information production (decrease of the degree of disorder or increase of the degree of order). In order to achieve the target of increasing the degree of order, the only means is to draw the negative entropy flow outside that system, or discharge the positive entropy flow from the inside to the outside of that system due to human activities. The South-to-North water transfer project (East Route) is an example of such large scale systems. Water transfer from the Yangtze River to the Huang, Huai and Hai

plains provides negative entropy flow as an input which reduces the degree of disorder and results in the improvement of the environment as well as economic and social benefits in the water importing region, owing to the provision of clean water. Due to the reduction of the flow of the Yangtze River, environmental problems will occur, such as sea-water intrusion in the estuary, the increase of concentration of pollutants in the water and the prolongation of the duration of waste water reverberation, etc. This yield of entropy flow results in decreasing the environmental benefit as well as economic and social benefits of the water exporting region.

These notions can also be applied to the Waste Water Discharge Project from the Huang Pu River to the Yangtze River which is being planned. Taking the Huang Pu River as an isolated system, waste water discharge represents the discharge of positive entropy flow from inside to outside of that system, reducing the degree of disorder, and resulting in an environmental improvement.

Large scale system theory postulates that the optimal state of the system must correspond with the state of minimum difference between the summation of the entropy reduction of subsystems and total entropy production of the large scale system:

$$\Delta S_{\text{Large system}} - \sum \pm \Delta S_{\text{subsystem}} = \text{min.}$$

Although the examples above are of the very first applications of the information theory and system approach to the environment related problems of large water projects of China, they have already been found to be especially useful in the area of strategic assessment of environmental impacts.

Besides, since economic analysis plays a very important role in decision-making, more attention must be given to an economic approach to environmental assessments to evaluate environmental impacts in monetary terms. In general, the economic approach should include: activity analysis, quantification of environmental impacts, monetization of the quantified impacts, and overall valuation of the monetized impacts. In this way, the total net benefit of water projects can be calculated as returns minus costs minus the value of the monetized impacts. The monetization techniques have been applied to the evaluation of the environmental impacts of China's South-to-North water transfer project (East Route), the Water Diversion Project from the Yellow River to Qingdao - a famous coastal city of Shandong Province, etc.

The Three-Gorges project is the largest construction project in China and famous throughout the world. The Three-Gorges, comprising Qutang, Wuxia and Xiling Gorge over a distance of about 200 km, provides several dam sites for multi-objective large water projects.

Early reconnaissance and planning of this project, carried out by Chinese engineers, including the author, goes back to the 1930s-1940s. The engineers of the US Bureau of Reclamation proposed a 10 560 MW scheme in 1944.

After the founding of the People's Republic, comprehensive planning, feasibility and design studies, including an environmental assessment, were made by Chinese engineers and scientists. The dam site finally adopted is located at Sandouping, 40 km upstream of the almost completed Gezuouba project, where sound granite bedrock, can accommodate the power-houses. Taking the 180 m scheme as an example, it will control a drainage area of 1 M km² (55 percent of the total catchment area of the Yangtze River), with a reservoir

capacity of about 20 Gm³ (1/23 of average annual runoff), and provide huge socio-economic benefits in the form of flood control, hydropower, navigation and tourism etc. It will also involve environmental impacts and ecological changes.

Apart from the economic aspects, the technical problems are numerous, such as geological and hydrological problems, sedimentation, power systems planning, large equipment design and construction, hydraulic structures, research and, above all environmental and ecological problems.

Of course, such a large water project on the largest river in China, with all its problems has been arousing worldwide interest and creating much debate both inside and outside of China, particularly with respect to environmental and ecological and associated problems.

The utmost effort has been made in the preparation of the environmental impact assessment of this project. The environmental and ecological studies have been shared between 48 research institutes and departments, supervised by the Yangtze River Basin Planning Office. Extensive investigations and evaluations have been carried out, including the adoption of a new modified matrix method in order to allow the identification of indirect effects of higher order and dynamic in character.

The main environmental problems of the Three-Gorges Project mentioned in the March 1985 report are:

1. Natural environmental aspects

- (1) hydrological regime
- (2) local climate
- (3) water quality
- (4) water temperature
- (5) reservoir sedimentation
- (6) erosion in downstream reaches
- (7) induced earthquakes and landslides
- (8) land resources
- (9) forestry
- (10) Flora and fauna
- (11) fishery

2. Socio-economic aspects

- (1) inundation by reservoir
- (2) migration and resettlement of population
- (3) historical and archeological places and sites
- (4) urban and industrial development
- (5) tourism and recreation
- (6) changes in agricultural production and supply
- (7) socio-economic conflicts between the workers and the resident population

3. Human health aspects

- (1) schistosomiosis
- (2) malaria
- (3) other water-borne diseases

4. Environmental and socio-economic aspects during the construction stage

5. Suggestions and Preliminary conclusions

The main preliminary conclusions of previous investigations are that the primary effects will be beneficial, especially those accruing from the main objectives of the project: flood control, hydropower production, navigation and tourism, etc.

In order to attain the ambitious target of quadrupling China's gross national product by the year 2000, flood control must be guaranteed along main rivers, amongst which the Yangtze River is the most important. Severe flood damage would severely affect the economic development of China and result in irremediable socio-economic and environmental consequences.

In this context, the Three-Gorges project will play a vital role in flood control in comparison with the other flood protection works or measures, such as reservoirs located on the tributaries or on the main river upstream, flood protection embankments of flood diversion channels downstream.

Apart from its technical aspects, the Three-Gorges project is of strategic importance in achieving the aim of quadrupling China's GNP by the year 2000. This target requires the production of large quantities of energy by exploiting from all sources, amongst which hydropower will play a very important role. Moreover it is clean from the point of view of environmental protection. The target obviously cannot be met by building small or medium hydro-projects at other dam sites or on the other rivers. Nor can it be met by increasing the number of streampower plants, which would create more environmental problems.

Thus, the Three-Gorges project, with all its favourable aspects and ideally situated to supply the Central region and East region of China, including the Delta region around Shanghai, which has limited reserves of coal and far surpasses other regions of China in industrial production.

Amongst the adverse effects, some are unavoidable, such as loss of land by inundation, migration and resettlement of affected populations. In the past not enough attention has been given to the relocation problem, but it has resulted in a deeper awareness that the success or failure of the Three-Gorges project hinges largely on a satisfactory solution to the relocation problem, including not only the migration and resettlement of large populations, but also the consequent social, economic and health problems associated with migration and resettlement. It is fully recognized that this is not a simple problem consisting only of allocating resettlement allowances and finding a place for them, but also of making proper arrangements for their resettlement. The solution must be far-sighted, so that the relocated people have a secure, long-term future in their new life, including homes and jobs. Some thought should also be given to possible tourist facilities near the historical and archeological sites.

Meanwhile, quite a number of adverse effects can be controlled, prevented, eliminated or reduced significantly in quantity and quality by appropriate measures during the process of planning, design, construction and operation. For example, the effects of sedimentation upon the navigation will be one of the important environmental impacts, so related research work and scientific studies have been given top priority and suitable measures will be taken during construction and operation. Due attention must also be given to environmental problems during the construction stage, such as noise, dust, waste liquids and water, waste

solids and slag, etc. It is also our experience that when buildings are put up for temporary use during the construction stages, they end up by being put to permanent use, their quality and appearance too frequently have a degrading effect on the environment. So the planning of buildings should cater for the possible permanent use of temporary buildings.

Man is the creator and moulder of his own environment, and large water projects demonstrate Man's interference with nature and also his wish to contribute to its development. So long as serious studies are made and lessons learned from the relationship between water resource development and the environment in the past, new water projects can be planned with a view to enhancing the quality of the environment whilst obtaining maximum economic, social and environmental benefits. There are no insurmountable problems prohibiting productive harmony between Man and the environment, so planners need not be biased against any type of dam construction.

Nothing is impossible in this world, if we dare to scale the heights (*Rien d'impossible au sein de l'univers, pourvu qu'on ose escalader la cime*). But the conclusion is that the environment must be treated as a critical dimension of large water projects rather than as an external parameter.

PAPER 29

LES TRANSFERTS INTER-BASSINS AU MAROC: UNE NECESSITE DICTEE PAR LES GRANDES DISPARITES REGIONALES EN MATIERE DE RESSOURCES EN EAU

*M. Noureddine Boutayeb*³⁶

Introduction

Pays à climat essentiellement semi-aride à aride, le Maroc comprend néanmoins une importante zone géographique relativement bien arrosée, constituée par les plaines côtières Atlantique Nord et surtout par les massifs montagneux de l'Atlas et du Rif situés au centre et au nord du pays. Ces massifs produisent la quasi totalité des écoulements souterrains et de surface. Ils sont drainés certes dans les quatre directions mais les principaux exutoires sont localisés dans la partie Nord-Ouest du pays qui concentre ainsi l'essentiel des ressources en eau, encore que cette concentration ne va pas sans entraîner quelques désavantages pour la partie en question puisqu'elle est souvent le siège d'inondations dévastatrices.

Les cours d'eau qui descendent de l'Atlas vers le Nord-Est, l'Est, le Sud et le Sud-Ouest, cheminent à travers des régions semi-arides ou arides extrêmement vulnérables aux aléas d'un régime hydrologique très irrégulier.

Historiquement, la vie sociale s'est organisée autour de points d'eau naturels sûrs et le long des rivières perennes à partir desquels les populations pouvaient s'approvisionner à longueur d'année pour leurs besoins propres, les besoins du bétail et dans certains cas les besoins d'irrigation. Les grandes sécheresses ont souvent été à l'origine d'importantes migrations saisonnières ou parfois définitives quand elles n'ont pas été la cause de bouleversements politiques.

Jusqu'à la fin du dix-neuvième siècle, la gestion des ressources en eau est demeurée marquée par l'aménagement traditionnel de petits périmètres d'irrigation à partir de sources ou de prises au fil de l'eau dérivant de faibles débits sur des terres avoisinant les cours d'eau, approvisionnement en eau des centres urbains à partir de ressources très proches, absence d'aménagements hydro-électriques.

Avec la colonisation du pays et les mutations sociales et économiques qui l'ont accompagnée au début du vingtième siècle, l'urbanisation et l'agriculture modernes se sont développées à un rythme accéléré. La satisfaction de la demande croissante en eau potable et industrielle exigea la mise en place de grands systèmes d'adduction d'eau dont les débits

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importants furent de moins en moins assurés par les ressources locales, d'où le recours à des ressources éloignées, situées parfois à l'extérieur des bassins concernés au premier chef.

Le développement de la grande irrigation comme moyen privilégié de mise en valeur de grandes plaines peu arrosées naturellement, devait nécessiter d'importants aménagements hydrauliques et hydro-agricoles.

Conçus et réalisés par l'Etat d'une part, appuyés d'autre part sur une législation nouvelle qui, prenant en compte le caractère de rareté de la ressource en eau, a incorporé au domaine public la quasi-totalité des eaux du pays, les nouveaux aménagements hydrauliques et hydro-agricoles se sont inscrits d'emblée dans le champ d'une politique de gestion visant à maximiser la valorisation du potentiel hydraulique. Sur la base d'un inventaire général des ressources en terre réalisé à l'échelle nationale, des périmètres d'irrigation devaient être implantés là où les conditions de mise en valeur étaient les mieux réunies. Le fait que ces périmètres soient appelés à recevoir des eaux du même bassin (proches ou éloignées) ou d'un autre bassin n'entraîne aucunement en ligne de compte. Il s'ensuit d'importants transferts intra-bassins et inter-bassins qui constituent des précédents historiques d'affectation inter régionale des ressources en eau du pays.

Quelques cas de transferts réalisés à la date d'aujourd'hui

Transferts dans le bassin de l'oued Moulouya

Situation avant transfert

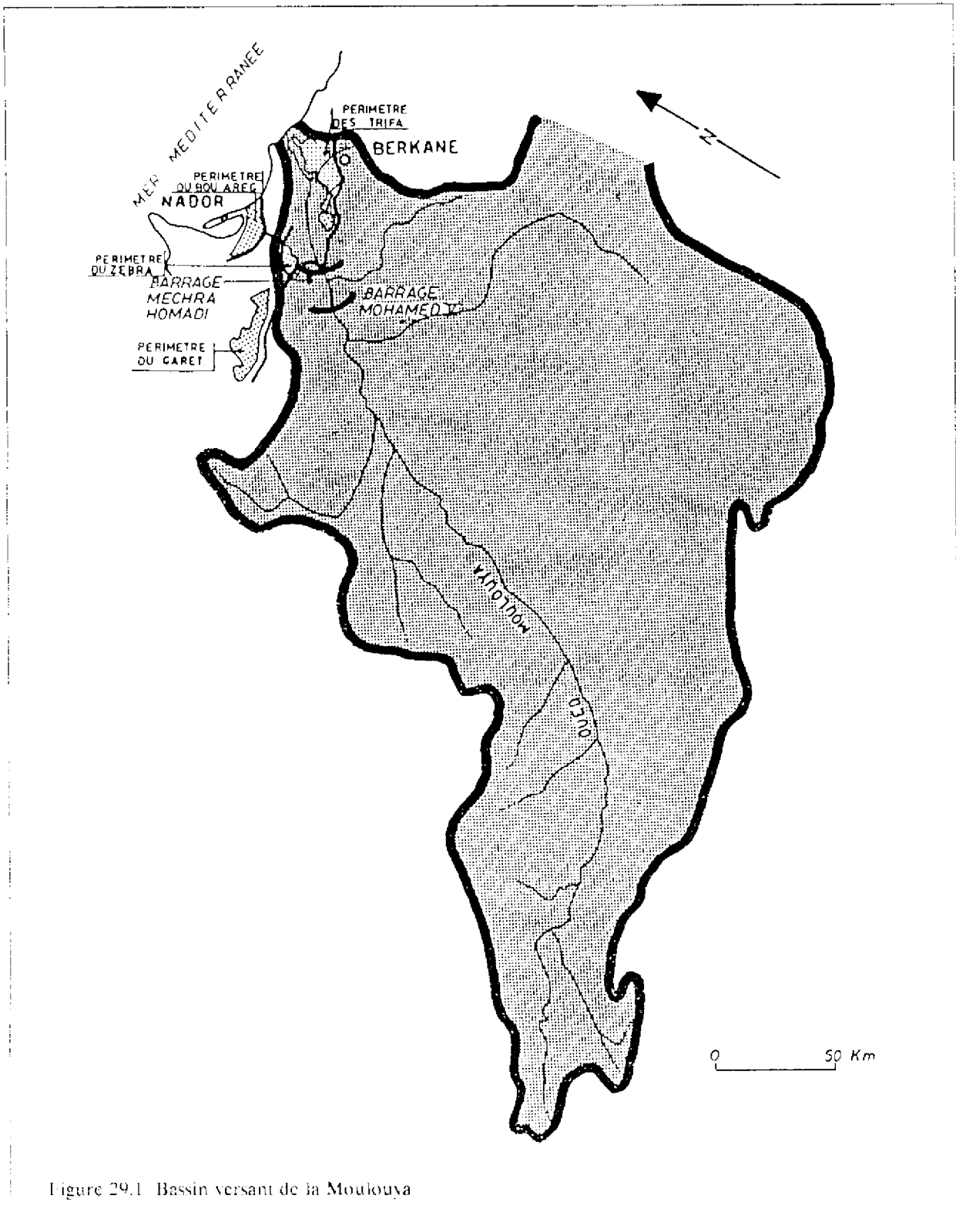
Long de 600 km, l'oued Moulouya est l'un des plus grands fleuves du Maroc (Figure 1). Il prend naissance à la charnière Nord-Est du Grand Atlas et du Moyen Atlas et se jette dans la Méditerranée non loin de la frontière algérienne. Son bassin couvre une superficie de 51 000 km² et reçoit des précipitations relativement faibles variant de 200 à 350 mm an⁻¹ en moyenne sauf dans le Haut bassin où elles atteignent 500 mm an⁻¹. Le régime de l'oued est très irrégulier et la variabilité des apports est aussi bien saisonnière qu'annuelle.

Jusqu'aux années 1920, les aménagements dans le bassin avaient intéressé exclusivement la haute vallée. Les prélèvements opérés à ce niveau, réduisaient davantage des étiages fort prononcés qui s'étalent sur une bonne partie de la saison sèche. Ne restaient ainsi pour la basse vallée que des apports de crue se produisant souvent en des laps de temps très petits.

La plaine littorale des Triffas bordée par le fleuve en basse vallée quoique représentant d'intéressantes ressources en terre tout en jouissant d'un climat très propice à l'irrigation n'avait pas été concernée jusque-là par les eaux de la Moulouya. Elle dut se contenter d'une agriculture basée sur la culture de céréales qui fit de moins en moins face aux besoins d'une population croissante.

Le projet d'aménagement de la basse-Moulouya

La plaine des Triffas située en rive droite de la basse Moulouya faisait partie dans les années 1920 de la zone sous occupation française. La rive gauche était quant à elle sous occupation espagnole. La récupération des eaux de crue dans la basse vallée de la Moulouya était convoitée tant par les autorités françaises que par les autorités espagnoles. Les unes entendaient transférer ces eaux à l'intérieur du bassin vers la plaine des Triffas, les autres entendaient opérer un transfert vers les plaines du Garet et du Bou Areg situées dans le bassin limitrophe du Kert dépourvu totalement de ressources pérennes.



Un accord est intervenu, entre les deux parties en 1927, pour fixer les modalités de mobilisation et de gestion. Au terme de cet accord un barrage d'accumulation allait être construit à frais communs au site de Mechrâa Klila dominant les deux zones promises à l'irrigation, les deux parties prenant à charge chacune pour ce qui la concerne la réalisation des canaux de transfert. Les volumes appelés à être régularisés ont été répartis à raison de:

6/10 pour les Triffas et 4/10 pour les plaines du Garet, Bou Areg et Zebra.

L'aménagement de la Basse Moulouya reçut un début de mise en service au début des années 1950 peu de temps avant l'indépendance du pays.

En permettant l'irrigation de 70 000 ha dans les provinces d'Oujda et Nador, il constitue aujourd'hui un bel exemple d'aménagement régional. En plus d'une mise en valeur agricole vitale pour la région orientale du Maroc, il assure une production d'énergie électrique importante, et fournit depuis quelques années de l'eau potable et industrielle à plusieurs centres urbains situés, comme les périmètres d'irrigation, les uns à l'intérieur du bassin les autres dans les bassins avoisinants. Les eaux de la Moulouya se trouvent ainsi réparties entre l'amont du bassin, son aval et le bassin limitrophe du Kert, contribuant de la sorte au développement harmonieux d'un vaste ensemble régional.

Les transferts vers le Baouz à partir du bassin de l'Oum Er Rbia

La plaine du Haouz est une vaste plaine alluvionnaire semi-désertique bordée à l'Est et au Nord-Est par le Haut et le Moyen Atlas (Fig. 2). Sans la présence des eaux souterraines et superficielles issues de l'Atlas, elle ne serait qu'un désert de galets et d'alluvions limoneuses tant la pluviométrie est insuffisante, les écarts de température importants (-4°C en hiver, plus de 50°C en été) et le degré hygrométrique bas au cours des mois d'été.

En plus de l'aménagement des piémonts entrepris par les populations depuis les temps les plus reculés, les Almoravides qui fondèrent la ville de Marrakech en 1062 imaginèrent de mettre en place aux environs de la ville, un réseau de plusieurs centaines de kilomètres de Khéttara (galeries captantes) destiné à drainer les eaux de la nappe pour les besoins d'une palmeraie de plus de 100 000 arbres qui n'a pas cessé depuis de contribuer à la prospérité de la cité, offrant ainsi un exemple éclatant de l'influence de la géographie physique sur la géographie humaine et sur l'histoire.

La mise en valeur progressive de tous les types de ressources en eau (souterraines, de surface, et épandage de crues) ne permit guère de répondre aux importants besoins d'irrigation de la région. Malgré la réalisation du barrage de Lalla Takerkoust en 1929, destiné à l'irrigation du périmètre du N'Fis, un important déficit subsistait au niveau de l'équilibre entre la ressource et la demande dans le bassin du Tansift. Ce déficit ne pouvait être atténué sans le recours à des ressources extérieures au bassin.

Et pour ce faire il n'y avait guère de choix : la ressource complémentaire ne pouvait être trouvée ailleurs que dans le bassin de l'Oum Er Rbia situé au Nord.

Les études de gestion réalisées sur ce bassin, l'un des deux plus importants du Maroc, avaient justement montré que le bilan des utilisations programmées restait excédentaire même après l'irrigation de près de 150 000 ha dans la plaine des Doukkala, située pour l'essentiel en dehors des limites du bassin.

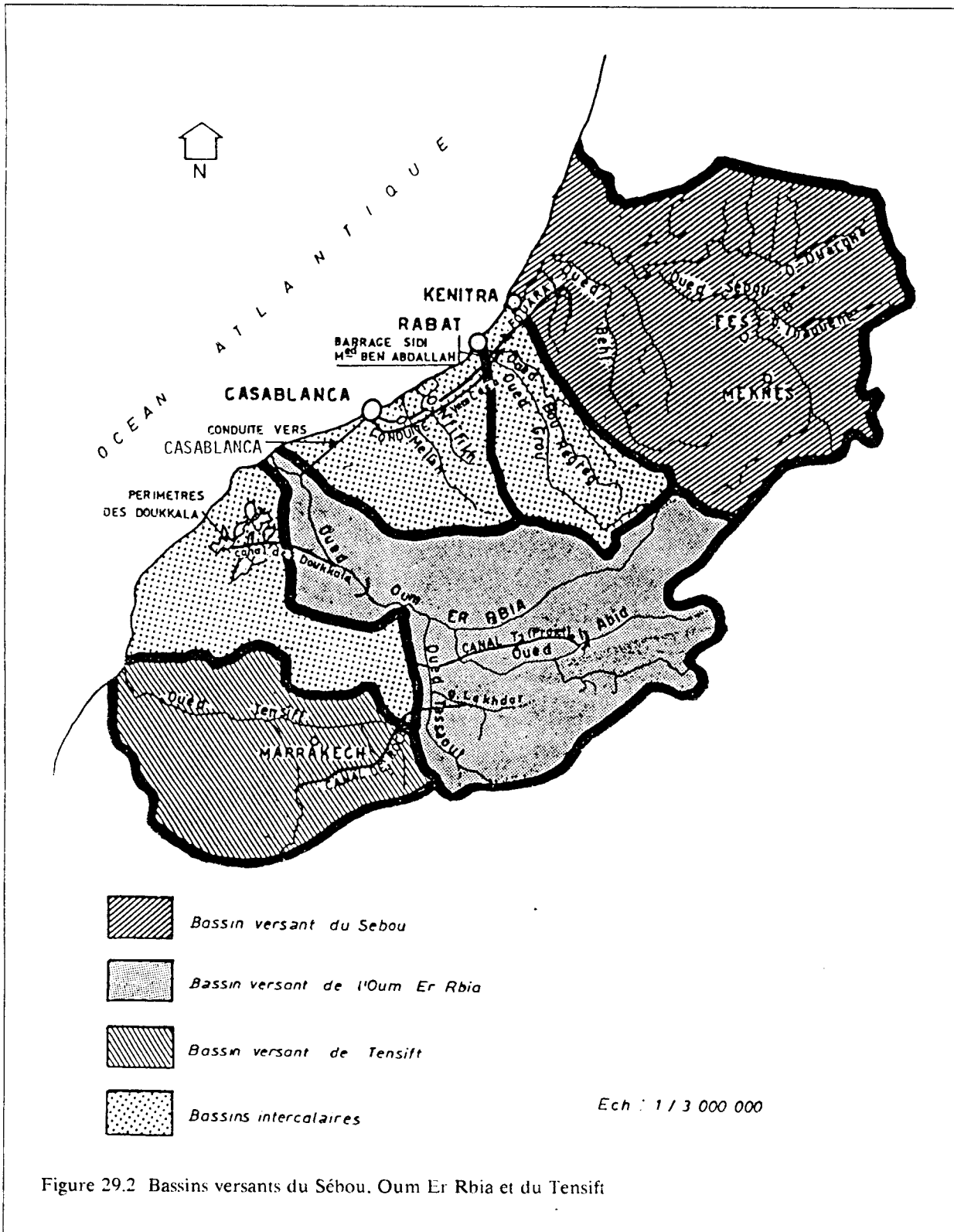


Figure 29.2 Bassins versants du Séhou, Oum Er Rbia et du Tensift

Boutayeb

Après un premier transfert pour le compte des Doukkala, un deuxième transfert a été reconnu possible pour alimenter le Haouz.

Le premier transfert est opéré à l'aval du bassin. Le deuxième devait être réalisé à partir du bassin amont.

Les dispositions techniques du transfert vers le Haouz

Le Haut bassin de l'oued Oum Er Rbia comprend du Nord au Sud les sous-bassins suivants: le Haut Oum Er Rbia, l'oued Al Abid et la Tessaout. La proximité du sous-bassin de la Tessaout l'éligeait tout naturellement à céder les volumes d'eau destinés au Haouz. Mais l'excédent d'eau à transférer était disponible non pas au niveau de la Tessaout mais de celui de l'oued Al Abid.

Le problème a été réglé par le truchement d'un transfert en deux étapes:

1 - Transfert de 300 Mm³ de la Tessaout vers le Haouz par un canal dérivant sur 130 km les eaux régularisées par le barrage Ait Chouarit.

2 - Transfert vers la Tessaout, à partir du barrage Bin El-Ouidane (sur Oued Al Abid) d'un volume équivalent par le biais d'un canal de 80 km.

Transfers pour le compte de la ville de Casablanca

La ville de Casablanca, dernière née des grandes citées Marocaines est devenue en moins de 30 ans la plus grande ville du pays. Promise dès sa création au rôle de capitale industrielle et économique par l'autorité coloniale, la satisfaction de sa demande en eau domestique et industrielle posa très tôt d'énormes problèmes. Il faut dire qu'à l'inverse de celle des anciennes agglomérations urbaines, son implantation n'avait, beaucoup s'en faut, pas reposé sur les conditions d'approvisionnement en eau.

Le petit bassin côtier à l'intérieur duquel est situé Casablanca disposant de ressources négligeables, l'approvisionnement en eau de la ville et de sa zone industrielle a dû être assurée dès 1932 à partir de la nappe du Fouarat située dans le bassin du Sebou à une distance de 140 km.

Vingt ans plus tard c'est au tour du bassin de l'Oum Er Rbia d'apporter sa contribution à travers une adduction d'eau de surface tirée sur 80 km à partir du barrage de Daourat. Enfin, depuis 1974, un troisième transfert est opéré à partir du bassin du Bou Regreg barrage de Sidi Mohamed Ben Abdellah.

Effets des transferts sur la gestion des ressources en eau

Aspects juridiques et économiques

Aspects juridiques et problèmes de droits d'eau

Les aspects juridiques de l'utilisation de l'eau au Maroc sont régis par la loi de 1914 complétée par la loi de 1979. Cette loi a été substituée à l'ancienne législation des eaux fondée sur le droit coutumier et caractérisée par une multitude de régimes juridiques, une législation moderne mieux adaptée aux exigences d'une gestion rationnelle des eaux.

En instituant le domaine public hydraulique auquel ont été incorporées toutes les eaux souterraines et superficielles, la loi a conféré à la ressource en eau un caractère d'unicité et de disponibilité à la mobilisation. Les pouvoirs publics, se sont ainsi donnés le moyen juridique nécessaire à la mise en oeuvre d'une politique de grands aménagements hydrauliques libérée des contraintes souvent inextricables des droits d'eau.

Les seuls droits d'eau reconnus sont les droits acquis avant 1914. En raison de leur très faible importance, ces droits n'ont constitué aucun obstacle à l'allocation des ressources en eau entre l'amont et l'aval des bassins, entre un bassin et un autre, entre un usage et un autre.

Aspects économiques

Les aménagements de transfert ont souvent mis en oeuvre d'importants investissements en ouvrages d'accumulation et de régularisation des eaux de crue, et en canalisation de transport dont les coûts sont accrus par les difficultés de passages souterrains en tunnel.

La combinaison d'aménagements hydro-agricoles et d'aménagements énergétiques par la réalisation des grands barrages à buts multiples a contribué certes à réduire la part des coûts imputables aux projets de transfert, mais les coûts propres de ces derniers sont demeurés quand même élevés.

Il importe de souligner toutefois que le coût important des équipements n'est pas une caractéristique propre aux projets de transferts inter-bassins, mais plutôt une caractéristique commune aux aménagements hydrauliques en général dans les régions arides et semi-arides.

Les transferts ne créent pas une problématique de la valorisation des ressources en eau, ils en étendent le champ et la portée.

Le problème de l'évaluation de la rentabilité des aménagements hydrauliques en général et des transferts en particulier réside dans la difficulté de l'évaluation des avantages générés par les projets, qui outre qu'ils présentent des aspects sociaux et politiques non chiffrables liés à des considérations de développement régional et inter-régional en interaction avec les objectifs de développement global, sont difficilement évaluables sur le plan purement économique. Le peu d'intérêt accordé en règle générale, au futur, conduit notamment à une forte sous-estimation des avantages appelés à être produits sur de longues périodes de temps. Un mètre cube d'eau produit dans 50 ans ou 100 ans correspondrait (respectivement) à 1/100 et 1/10 000 de m³ produits aujourd'hui pour le taux d'actualisation usuel voisin de 10 pourcent.

Le choix des projets de transferts réalisés jusqu'à présent a procédé de considérations économiques traduisant une volonté d'accroître le revenu national par le développement des irrigations mais aussi dans une large mesure de considérations sociales liées aux exigences du développement régional et inter-régional en interaction avec les objectifs de développement global du pays.

Conséquences sur les équilibres demande-ressources à l'échelle du bassin et à l'échelle régionale

La politique de transferts amont-aval au sein d'un même bassin et d'un bassin à un autre mise en oeuvre sur l'ensemble du territoire depuis un peu plus d'un demi-siècle, se traduit aujourd'hui par une nouvelle carte des utilisations des ressources en eau marquée par l'aménagement hydraulique de vastes régions arides dont le développement économique et social a longtemps été freiné par la rareté ou l'indisponibilité des ressources en eau.

Les transferts d'eau devaient porter sur des ressources excédentaires ou du moins jugées comme telles.

Procédant d'une stratégie de développement économique et social inter-régional dont la mise en valeur des terres par l'irrigation a constitué et continue de constituer l'élément moteur, ils ont été conçus sur la base d'une confrontation à l'échelle régionale des ressources en terres et des ressources en eau disponibles dans les bassins correspondants ou dans des bassins avoisinants.

Ils n'ont de la sorte pas porté uniquement sur des excédents au sens où ce terme est entendu habituellement, savoir les volumes de crues d'inondations et les excès se perdant à la mer dont l'aménagement au sein du bassin est considéré comme ne présentant aucun intérêt. Ils ont reposé sur des bilans inter-régionaux.

C'est ainsi que les eaux mobilisables du bassin de l'Oum Er Rbia ont été entièrement réparties entre les différents besoins inventoriés dans le bassin (grands périmètres des Béni Amir et des Béni Moussa, Petite et Moyenne Hydraulique, etc...) et dans les bassins avoisinants (Périmètres du Haouz et des Doukkala, etc...). Or les bilans prévisionnels d'utilisation des eaux ont été établis pratiquement au vu des seuls besoins de l'irrigation, qui ont représenté par le passé plus de 95 pourcent des besoins globaux.

Prenant en compte les demandes en eau domestique et industrielle qui ont enregistré un important accroissement depuis l'indépendance du pays, les études de planification réalisées au milieu des années 1970 sur le même bassin ont conclu à la saturation des ressources du bassin vers l'horizon 1995. La longue sécheresse qui a frappé le Maroc entre 1980 et 1985 a davantage mis en relief le caractère précaire de l'équilibre des ressources et des besoins dans cet important bassin autrefois traité comme le "donateur universel".

Il se trouve fort heureusement que des possibilités de transfert existent dans le bassin voisin, à savoir le Sebou, encore faiblement équipé.

Relation entre équilibre des ressources et des besoins à l'échelle du bassin et équilibre à l'échelle régionale

En tout état de cause, l'équilibre à l'échelle du bassin n'est affecté par les transferts vers d'autres bassins que si ces derniers ne portent que sur des volumes de crues d'inondations sources de dégâts économiques ou environnementaux ou sur des excès perdus à la mer.

Le transfert des eaux de crues d'inondation pose le problème de l'évaluation des dommages économiques et environnementaux à long terme et des actions de nature à y remédier.

Le transfert des excès perdus à la mer pose quant à lui le problème de la détermination du débit pouvant être considéré comme se perdant à la mer, étant bien entendu que les besoins du bassin, augmentant dans le temps, les débits perdus à la mer ne seront pas les mêmes dans 50 ans que dans 100 ans. Leur valeur sont d'autant plus faible que l'horizon de la prévision est éloigné.

Est-ce à dire que l'on doit s'interdire d'envisager des transferts à partir de bassins dont l'excès à la mer sera nul dans 100 ans, vers des bassins déficitaires aujourd'hui? Est-il sensé de laisser se perdre à la mer des eaux qui ne seront utilisées dans leur bassin d'origine que dans plusieurs dizaines d'années alors que ces eaux seraient d'une grande utilité dans un autre bassin? On se heurte là à un problème majeur qui ne peut trouver une juste solution que dans le cadre d'une planification des eaux à long terme à l'échelle de l'ensemble des bassins concernés dans un sens et dans l'autre par des actions de transferts.

Effets en période de sécheresse

Le Maroc vient de traverser au cours de la période 1980-1985 (1975-1985 pour certaines régions du Sud) une sécheresse extrêmement sévère. Dans l'ensemble des bassins, les ressources en eau ont été affectées et leurs gestion sérieusement perturbée. Mais ce sont les zones arides du Sud notamment qui ont le plus souffert. Plus qu'en période humide, les transferts d'eau des régions les mieux arrosées vers les régions qui le sont moins (Triffa, Guret, Bou Areg, Doukkala) se sont avérés d'une nécessité vitale pour le devenir de ces régions.

Ils ont certes plus ou moins accentué les déficits dans les bassins d'origine, mais le manque à gagner est très largement compensé économiquement et socialement parlant par une haute valorisation des eaux transférées vers des zones absolument démunies.

Les transferts inter-bassins, volet essentiel du plan national des eaux du Maroc

Des études préliminaires de bilans ressources-besoins réalisées à la fin des années 1970, il devait se dégager que nombre de bassins, dont celui de l'Oum Er Rbia, allaient connaître à des échéances plus ou moins rapprochées une saturation de l'ensemble de leurs ressources sous la pression des demandes croissantes en eau domestique et industrielle, insuffisamment prises en compte par les plans d'aménagement antérieurs.

L'interférence des systèmes de transfert dans les bilans actuels d'utilisation des eaux des principaux bassins du Maroc, et les déséquilibres se profilant pour les prochaines décennies ont largement inspiré les termes de référence de l'étude lancée en 1982 pour l'établissement du Plan National des Eaux, dont le schéma d'aménagement intégré des bassins Sebou, Bou Regreg, Oum Er Rbia et Tensift (S.B.O.T.) élaboré dans une première étape, constituera la pièce maîtresse.

Ce grand ensemble qui a déjà été par le passé le théâtre des plus importants transferts opérés à partir du bassin de l'Oum Er Rbia situé au centre, vers le Sud, offre aujourd'hui encore de grandes possibilités de transfert à partir du Sebou vers les bassins du centre et du Sud. Le bassin du Sebou occupe, au sein du grand ensemble régional situé à l'Ouest de l'Atlas et constitué principalement par les quatre grands bassins précités, une position

privilegiée sur les plans géographique et climatique. Il présente la particularité d'avoir le taux d'équipement hydraulique le plus faible des quatre grands bassins, Sebou, Bou Regreg, Oum Er Rbia et Tensift, tout en renfermant 50 pourcent de la ressource disponible.

Cette situation résulte de ce que:

- la pluviométrie étant importante et la valeur ajoutée par l'irrigation relativement faible, comparativement à d'autres bassins, l'aménagement hydro-agricole a été développé avec un certain retard.

- la demande en eau potable et industrielle de la région s'est développée principalement dans la zone côtière Rabat-Casablanca-Safi située en dehors du bassin.

- l'aménagement hydraulique du bassin est fortement lié à des considérations de protection contre les inondations dont l'évaluation des effets et des mesures pour y remédier n'est pas sans poser de sérieuses difficultés quant au choix des investissements à engager.

Ce dernier aspect du problème de l'aménagement du Sebou, trouvera justement une meilleure évaluation dans le cadre d'un aménagement régional.

Alors que les plans d'aménagement antérieurs avait visé une mise en valeur des ressources du bassin à l'intérieur des limites naturelles de ce dernier qui devait être assurée moyennant un taux d'équipement voisin de 55 pourcent, le plan d'aménagement intégré des quatre grands bassins Sebou, Bou Regreg, Oum Er Rbia et Tensift visera une allocation des ressources globales des quatre bassins mettant à contribution les ressources du Sebou de manière à assurer un équilibre des ressources et des besoins au niveau du grand ensemble.

La notion d'équilibre régional, prise en compte dans le contexte de la répartition de la ressource et de la demande au sein des quatre bassins, implique que la demande propre du bassin du Sebou soit projetée à un horizon qui est le même que celui de la saturation de l'ensemble des ressources sur les quatre bassins. Ceci permet de résoudre la difficulté signalée plus haut provenant du fait que les quantités d'eau transférables à partir d'un bassin dépendent de l'horizon de la prévision de la demande sur ce bassin.

Il reste que l'horizon étant défini, l'importance des transferts est déterminée par la répartition géographique des différentes demandes futures.

Cette répartition est examinée au regard d'une gestion inter-active de la demande et de la ressource prenant en compte:

- les actions possibles sur la demande aussi bien d'irrigation (exemple: développement de l'irrigation davantage dans les bassins du Sud à faible pluviométrie et réduction des irrigations programmées jusqu'à présent dans le Sebou) que d'eau potable et industrielle (politique volontariste d'implantation humaine et industrielle combinant déplacement de la ressource et déplacement de la demande).

- les possibilités d'une utilisation en chaîne de la ressource en eau allant, d'amont en aval, des usages les moins consommateurs (énergie, eau potable) vers les usages les plus consommateurs, (industrie, irrigation) permettant par le truchement des réutilisations et recyclages, de mieux adapter la demande nette aux potentialités en eau.

Conclusion

Dans les conditions géographiques et climatiques du Maroc, le développement des irrigations comme moyen privilégié de mise en valeur agricole, a nécessité dès les années 1930 d'importants transferts d'eau des bassins bien arrosés vers des zones arides ou semi-arides.

A une importante demande en eau d'irrigation est venue s'ajouter au cours des dernières décennies, une demande en eau potable et industrielle caractérisée par une forte croissance et par son implantation dans des bassins dont les ressources atteignent la saturation sous l'effet conjugué d'une demande propre et des transferts opérés ou programmés vers d'autres bassins.

L'étude de la demande future et des bilans prévisionnels des ressources et des besoins montre que les transferts inter-bassins sont appelés à occuper une place de premier ordre parmi les aménagements hydrauliques à venir.

La définition d'une stratégie de mise en valeur des ressources en eau prenant en compte les exigences de transferts et leurs implications économiques et environnementales passe par l'établissement de schémas d'aménagement intégré à l'échelle d'ensembles de bassins comme première phase de l'élaboration d'un plan national des eaux.

PAPER 30

ENVIRONMENTAL MANAGEMENT OF THE ZAMBEZI RIVER SYSTEM

*L.L. Mbumwae*³⁶

1. Introduction

It has now become imperative for those of us in developing countries to look for and satisfy the needs of our populations with basic food, water and shelter. In order to achieve this, we have to harness available energy sources such as coal, gas and hydropower. Inevitably, such development activities will have an impact on our environment. Some of these impacts may enhance the environment while others may be harmful.

As we exploit these resources, we must strive to achieve a proper balance between resource development for a high standard of living and maintenance of the quality of the environment. This is rightly so because as we increase our wealth and comfort we should not have to fear that in future we shall have to use all our wealth to regain our health.

With this objective in view, the integrated programme on Environmentally Sound Management of the Common Zambezi River System was launched by UNEP, in collaboration with other UN Organizations, to assist Governments to develop regional cooperation and promote the sustainable development of the Zambezi River Basin. The Zambezi River programme is not only aimed at a systematic investigation of environmental impacts of development, but also to ensure that properly designed policies and programmes are formulated by riparian countries.

The various regions of the Zambezi River Basin are linked not only by their political, social and economic relationships, but also by the very fact that they draw on the resources of the same river basin and have similar environmental conditions. Watershed deforestation in one country within the basin may be the cause of flooding and sedimentation in another.

2. Background

The Zambezi River Basin includes the territories of the eight following countries: Angola, Botswana, Malawi, Mozambique, Namibia, Zambia and Zimbabwe. The Zambezi River catchment area is about 1.3 M km², while the total length from its source to the Indian Ocean is about 3 000 km.

The total estimated population within the river basin and its tributaries is about 20 million inhabitants, within the South-central African Plateau of the Central African Rift.

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The present cooperation amongst basin states is mainly linked with economic development activities through the Southern African Development Cooperation Conference, SADCC, hydropower generation from existing intergovernmental agreements and through communication links (roads and railways).

Competition for water use and utilization of the river has not arisen whether now or in the past. Present demands for water use include hydropower generation, irrigation development and drinking water supply. The use of water for power generation was developed after construction of the Iteshi-teshi and Kafue dams on the Kafue River and Kariba and Cabora Bassa dams on the Zambezi River. Many other smaller dams exist within the basin on tributaries of the Zambezi River. The presence of these dams and their operation have without doubt altered the hydrological regime of the basin, with consequences for wildlife, animal husbandry plant and bird life.

The environmental impacts of such development activities call for urgent attention and for their being given due weight in future decision-making, in a coordinated manner so as to avoid possible future conflicts. Only better insight into the precise nature of various regimes in the basin and the impact of different measures on interacting systems, can form the basis for balancing conflicting interests in assessing the feasibility of any future proposals by different development activities.

3. Objectives of the Zambezi River Project

The main objectives for the sound management of the Zambezi River System are based on the diagnostic study of country reports submitted by Angola, Botswana, Malawi, Mozambique, Namibia, Zambia and Zimbabwe. The diagnostic study defined specific environmental problems and their impacts and outlined management goals, policies and current situations and activities within the Zambezi River Basin.

In the light of the diagnostic study, the main problems related to sound management of the river basin were identified:

- lack of monitoring with regard to climatic data, water quality and pollution control;
- soil erosion and lack of adequate water and soil conservation and flood plain management;
- deforestation due to population growth and pressure on the land;
- lack of potable drinking water supply and proper sanitation and community planning in construction, maintenance and health education;
- inadequate human resources development;
- lack of coordination both at national and river basin levels;
- degradation of flora, fauna and landscape;
- impacts on hydro-electric power and other energy development;
- lack of dissemination and exchange of information.

4. Action Plan for the Zambezi Project

The theme for action on the Zambezi is that development activities and environmental management are two sides of the same coin. It therefore follows that environmental assessment, its management and legislation, represent key elements in the plan of action of this project. The activities which require immediate implementation have been identified and are described in Appendix 1, within the framework of the Zambezi Action Plan.

The decision has been taken that any such project within the plan of action, shall be mutual to at least two or more basin countries and shall be closely related to intergovernmental cooperation in management of water resources, i.e. monitoring, networks, pollution control and legislation. Furthermore, a training and information component at different levels shall be incorporated while the aspects of an improved environment and economic development shall also be investigated.

5. Zambia's National Conservation Strategy

Zambia's reliance on copper mining has become a severe constraint to development for a host of reasons. In view of this, the Government has changed the emphasis in development from mining to agriculture, in the light of the need to develop the potential of renewable natural resources for alternative development activities.

At present, certain conservation programmes are carried out, but it is evident that the level of investment is below that which is required to ensure sustainable development. It is in this context that the National Conservation Strategy has been formulated. It involves policies, plans, organization and action for the better management of Zambia's vast but fragile natural resources. The strategy aims at providing firmer ground on which decisions for national development can be taken. Of particular importance is to emphasize the need for adding an environmental dimension for development planning. This means that all national project proposals will involve the Ministry of Finance, National Commission for Development Planning (Department of Economic and Technical Cooperation) at all project stages. The initial input is critical in the terms of reference of feasibility studies to ensure that relevant questions on environment are answered.

5.1 Draft Environmental Council Act

An Act to establish an Environmental Council in the Republic of Zambia has been drawn up and it is under discussion.

At present there is only one law relating directly to natural resources conservation for many sectors (the Natural Resources Act Cap. 315). This and other legislation concentrates upon restricting certain practices in order to avoid damage to resources and the environment. However, both the power and the enforcement of existing legislation are extremely weak. The Water Act Cap. 312, merely makes it an offence to pollute water rather than prescribing mandatory abatement.

6. Conclusions

It can be stated without a doubt that the integrated development of the Zambezi River Basin will lead to a host of achievements, in line with UN General Assembly resolution of 1967 for Africa in the Mar del Plata Action Plan. These achievements, among others, are described below:

6.1 Optimum utilization of shared water resources will promote economic integration and cooperation among the Zambezi states.

6.2 Multilateral cooperation and coordination will only be successful in so far as it reinforces national programmes and vice-versa.

6.3 the Zambezi River project has clear-cut objectives which should be supported by riparian countries in the form of material and financial contributions, and this in turn will attract external funding. There is little point in promoting organizations which are not founded on definite cooperative programmes.

6.4 There is an obvious lack of exchange of information in water resources within the Zambezi River Basin. Most information comes from the international periodicals of the developed world. Therefore, cooperation amongst Zambezi countries will only enhance dissemination of successful technologies. One technology may not work in one country, but could be made to work in another. This approach will help to eliminate costly mistakes.

6.5 A common goal for water resources assessment and development in the Zambezi River Basin will also lead to standardization of methodology and technology of water resources development.

6.6 The Zambezi Basin network for water resources assessment is also intended to address both qualitative and quantitative aspects of water, in particular issues related to monitoring the quality of both surface and groundwater, which does not exist at present.

APPENDIX I

PROGRAMME PRIORITIES FOR THE ZAMBEZI ACTION PLAN (ZACPLAN)

The Zambezi Action Plan Projects (ZAPP) which are to be implemented during the first phase (1987-89) are as follows:

ZAPP 1 - Up-to-date compilation of all completed, ongoing and planned projects which can be related to the ZACPLAN including the evaluation of major key projects which have been implemented, in order to gain experience and to avoid mistakes for future project implementation.

ZAPP 2 - Up-to-date compilation of national laws related to the protection of water and the environment.

The development and adoption of regional conventions for the protection, management and development of water, other natural resources and the environment.

Technical assistance and advice on the drafting of national legislation for the effective implementation of regional conventions and their protocols.

ZAPP 3 - Survey of national capabilities and means to respond to environmental problems including scientific and administrative institutions, manpower requirements, research facilities and equipment and the need for human resources development.

ZAPP 4 - Development or strengthening of national research institutes, laboratories and institutions in order to enable them to carry out water- related environmental research and training.

ZAPP 5 - Development of basin-wide unified monitoring systems related to water quality and quantity, including pollution control.

ZAPP 5/1 Review of relevant information related to climatological and hydrometric networks, streamflow records, rainfall distribution, plant water consumptive use, groundwater resources, water analysis, sediment transport and pollution control.

ZAPP 5/2 Development of basin-wide unified monitoring systems, based on ZAPP 5/1.

ZAPP 5/3 Establishment of a River Basin Environmental Data Bank in conjunction with the establishment of national data banks.

ZAPP 5/4 Assessment and evaluation of the need for electronic data processing within the River Basin States as related to the ZACPLAN in general and to the data bank in particular.

ZAPP 5/5 Promotion of a fuller utilization of existing mechanisms for a continuous exchange of water-related environmental data and other relevant information between the countries at the regional and sub-regional level.

ZAPP 6 - The design and implementation of campaigns to persuade communities and individuals to promote:

good sanitary facilities

soil conservation measures

forest protection and wood-fuel plantations

These campaigns should be based on past experience in some of the river basin States which may have carried out such campaigns in the past.

Special emphasis should be laid on proper operation and maintenance procedures and training of personnel at all levels.

ZAPP 7 - Basin-wide harmonization of methodologies regarding environmentally sound management and their application to decision-making for drinking water supply, sanitation, irrigation and hydropower projects.

II. The following project should be implemented as soon as funds and human resources are available:

ZAPP 8 - Development of water Master Plans based on sub-basins as a first phase, later expanding to cover the whole river basin.

ZAPP 9 - Development and strengthening of the capability of the nations of the region to prepare environmental impact analyses for major development projects in order to incorporate the environmental dimension in the planning and implementation of socio-economic development programmes.

ZAPP 10 - Promotion of increased technical and financial support for sound environmental management practices within on-going national, regional and internationally supported economic development activities so that these may have a demonstrative effect.

ZAPP 11 - the energy projects listed below should be implemented in close cooperation with the SADCC Energy Secretariat.

ZAPP 11/1 Assessment of major sources of conventional and non-conventional energy and their potentials for utilization within and outside the river basin.

ZAPP 11/2 Assessment of the potential for energy conservation measures in the fossil fuel and hydropower energy production systems and use and formulation of guidelines and recommendations on measures to achieve optimal efficiency in the exploitation of these resources.

ZAPP 11/3 The feasibility of linking the major hydropower plants together with marketing analyses.

ZAPP 11/4 Environmental Impact Assessments for existing and potential energy schemes which are likely to be developed or to be selected for further studies.

ZAPP 11/5 Implementation of field demonstration projects on improved wood fuel utilization and application of other renewable sources of energy, including measures to ensure adequate replication throughout the river basin.

ZAPP 12 - Adoption of watershed management guidelines based on the assessment of the effects of modifications of the relationships between forest cover, water and land use with a view to introducing environmental planning concepts in the management of catchment areas, particularly in rural areas exposed to soil erosion.

ZAPP 13 - Implementation of watershed management pilot and promotion projects in different parts of the river basin. Their implementation should be based on the guidelines adopted under ZAPP 12 above. Soil erosion and siltation studies should be carried out before and after implementation in order to evaluate impacts of the the projects.

ZAPP 14 - Prevention and control of water-borne diseases in the Zambezi Basin. Health projects listed below should be implemented in close cooperation with WHO and local health institutions.

ZAPP 14/1 Evaluation of information on the endemic water-borne diseases in the Zambezi River Basin.

ZAP 14/2 Guidelines on health safeguards in planning, design, construction and operational phases of water resources development projects in the Zambezi River Basin.

ZAP 14/3 Guidelines on the prevention and control of water-borne diseases in the Zambezi River Basin.

ZAP 14/4 Seminar on prevention of water-borne diseases in the Zambezi River Basin and promotion of training of technical personnel involved in water projects as a follow-up to this seminar.

ZAPP 14/5 Promotion of community awareness of prevention and control of water-borne diseases in the Zambezi River Basin, utilizing mass media and community level education.

ZAPP 14/6 Pilot project on the control of water-borne diseases in the Zambezi River Basin.

ZAPP 15 - Limnological studies of Lake Malawi, Lake Kariba, Lake Caborra Bassa and Lake Chilwa.

Special attention should be given to fisheries and the creation of fish farms.

ZAPP 16 - Genetic resources programmes for the Zambezi Action plan.

ZAPP 16/1 Establishment of a self-supporting network of centres for collection, evaluation, conservation, documentation of seeds of multipurpose arboreal species of the arid and semi-arid zones and their application to rural development and desertification control.

ZAPP 16/2 Establishment of a regional gene bank for conservation of crop and forest germplasm and their application to agricultural and forestry improvement.

ZAPP 16/3 Establishment of technical and administrative capabilities for conservation and management of fish genetic resources.

ZAPP 17 - Development and application of ecologically acceptable methods of tsetse-fly control in the Zambezi River Basin.

ZAPP 17/1 Survey of on-going operations for tsetse fly control by pesticides and assessment of their impact on human, and livestock health and upon the environmental.

ZAPP 17/2 Development and testing of a model integrated package for the control of the tsetse fly and promotion of its field application at the regional level (pilot demonstration project).

ZAPP 17/3 Promotion of environmental training as a corollary to tsetse-fly control with insecticides (within the context of FAO training applied research for Glossina control in the Dry Savannah Zone - FAO Training Centre, Lusaka).

ZAPP 17/4 Development of guidelines for ecologically sound control of the tsetse fly in the Zambezi River Basin.

ZAPP 18 - development of unified water engineering planning and design criteria for major elements including non-piped and piped drinking water supply and sanitation schemes together with appropriate treatment when required.

ZAPP 19 - Establishment of a coordinating Zambezi River Basin Organization.

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THEME III

**IMPACTS ON MANY SMALL SCHEMES OVER A LARGE AREA, SUCH AS SMALL
IMPOUNDMENTS AND THEIR IMPLICATIONS FOR WATER MANAGEMENT POLICIES**

PAPER 31

ETUDE ACTUALISEE DE L'ENVASEMENT DES RETENUES DES BARRAGES DU MAROC

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Resumé

Après avoir analysé les diverses méthodes utilisées au Maroc pour la détermination de l'envasement des retenues de barrage (bathymétrie, turbidimétrie, photographie aérienne, topographie, etc...), cette étude met en relief les lois obtenues, liant les dégradations des bassins versants à leurs surfaces ainsi qu'à leur lithologie dominante, aux lames d'eau écoulées et à d'autres paramètres.

Elle débouche enfin sur l'établissement d'une série de formules de prévision du taux de comblement des barrages à implanter ultérieurement dans n'importe quelle région du Maroc, et pour diverses lithologies dominantes du substratum.

Introduction

Le rythme accéléré de la mise en valeur des ressources hydrauliques en vue de mettre au point des aménagements hydrauliques, nécessite, de plus en plus une connaissance approfondie de l'érosion, du transport solide et de l'envasement des lacs réservoirs.

L'analyse des pertes en eaux et sols, les moyens de défense pour la restauration de ces derniers, la connaissance des dégradations des terres dans les bassins versants à l'amont des barrages, du dépôt et du transit des matériaux solides dans les ouvrages: retenues, canaux, lacs naturels, bassins amortisseurs, érosion des pales de turbines, alluvionnement des ports, a ouvert de nouvelles perspectives pour l'étude de l'érosion, du transport et du dépôt de sédiments.

Il faut signaler qu'heureusement ces demandes d'analyse du phénomène de l'érosion, du transport solide et de l'envasement des barrages, ont abouti au Maroc, à la mise sur pied, au cours d'une dizaine d'années, de nouvelles techniques appropriées.

C'est ainsi que de nouvelles méthodes d'investigation de l'alluvionnement des cuvettes de barrages, ont été instaurées, ainsi que des activités telles que la photogrammétrie aérienne et la bathymétrie (largement utilisée actuellement).

Des méthodes de pointe ont été mises en oeuvre pour la connaissance des matériaux se déposant dans les retenues de barrages.

Généralités

L'étude du mécanisme de l'envasement de la cuvette des barrages et le mode de formation des accumulations de vase atterrissant dans la tranche morte, résultent aussi des mesures de sédimentations.

Les divers types d'érosion, (splash en nappes, en griffes et ravinantes), sont à l'origine de ces transports solides en suspension, lesquels se développent dans un système constitué, d'une part, par l'élément bassin (en oued) caractérisé par sa perméabilité, sa nature lithologique, l'intensité du relief, sa végétation et, d'autre part, par l'élément moteur du transport solide, à savoir l'eau, qui agit par son énergie cinétique d'impact et sa capacité d'érodabilité, ainsi que par son ruissellement.

Divers paramètres conditionnent la formation de ces transports de matières terreuses et leur évolution dans le temps. Pour ne citer que quelques uns de ces facteurs, mentionnons les conditions initiales à savoir: l'humidité antérieure du sol, l'intensité des précipitations pluviales, la période de l'année dans laquelle s'effectue le transport solide, la nature géologique du bassin versant, et la lame d'eau ruisselée. Tous ces paramètres liés entrent simultanément en jeu et il est difficile d'en isoler un pour dire qu' il est le seul à prendre en considération.

Méthodes utilisées pour la détermination de l'envasement

Les diverses méthodes directes utilisées en vue de déterminer l'envasement des retenues des barrages du Maroc sont:

- méthode turbidimétrique aux stations hydrométriques,
- méthode stéréophotogrammétrique,
- méthode topographique,
- méthode de vidange et de remplissage,
- utilisation de courbes de dégradations en fonction des surfaces de bassins versants, appliquées dans des bassins plus ou moins similaires, dans le cas où aucune des méthodes précitées ne peut être utilisée (inexistence d'une station hydrométrique amont ou absence de données suffisantes).

a) Procédés bathymétriques

Les mesures directes de la profondeur donnent des résultats très précis, mais au-delà d'une dizaine de mètres, leur exécution devient laborieuse. Aussi a-t-on recours aux mesures indirectes que permettent les bathymètres.

Le bathymètre est un instrument de mesure electro-acoustique basé sur la vitesse de propagation du son dans l'eau, soit 1 800 m par seconde, l'impulsion ultrasonore émise est renvoyée et enregistrée chronométriquement sur papier et s'inscrit sous forme d'une ligne continue qui reproduit le profil du fond immergé.

L'industrie électro-acoustique a mis à la disposition de l'ingénieur des sondeurs enregistreurs adaptés aux gammes de profondeurs qui nous intéressent.

Dans la gamme de 0 à 40 m, l'échelle de reproduction des hauteurs est de 1 mm sur le papier pour 135 mm, ce qui nous donne une erreur qui reste acceptable pour un profil continu. La vitesse d'avance automatique du papier est réglable à volonté jusqu'à 480 mm par minute.

Les opérations de relevés des profils utilisent les méthodes de repérages topographiques et le plan d'eau sert de référence altimétrique. La distance parcourue par le bateau est contrôlée par des visées issues de deux théodolites stationnés de part et d'autre du profil. Cette opération qui permet ensuite la remise à l'échelle des longueurs du graphique s'exécute à l'initiative du pilote qui fait relever sa position par "top radio" ou par signe direct aux opérateurs latéraux.

b) Méthode turbidimétrique

Durant chaque crue, à chaque instant, on mesure la hauteur d'eau à la station à laquelle correspond un débit liquide instantané Q (déterminé à partir de la courbe d'étalonnage). La concentration de l'échantillon pris à cet instant est mesurée par double pesée au laboratoire. En multipliant cette concentration par le débit liquide instantané, on obtient le débit solide instantané et durant toute la crue. On trace le turbidigramme dont le planimétrage donne la masse solide transitée pendant l'année, durant toutes les crues, et on effectue une distribution fréquentielle par les lois statistiques (incomplète, Galton, Gibrat, Pearson III, etc..) des masses solides transitées durant les années d'observation.

c) Détermination de la dégradation spécifique moyenne annuelle à partir de la stéréophotographie aérienne

L'un des procédés actuels les plus précis pour établir les données de base est la stéréophotographie aérienne complétée, au sol, par un travail de triangulation et de stéréopréparation topographique. L'erreur commise par ce procédé, dans l'évaluation des coordonnées des points particuliers, est de l'ordre de 0.10 m. Une telle précision nous a permis d'utiliser cette technique pour déterminer et mesurer avec précision l'engravement des retenues par réitération de photographies semblables à des intervalles suffisants, de l'ordre de 5 ans ou même de 2 ans. Cette méthode est particulièrement utilisée en période de sécheresse, quand la retenue est à niveau bas.

d) Vidange et remplissage

La vidange décennale du barrage Méchra Homadi a été réalisée en février 1975, définissant le nouveau volume utile en cette période, à la cote normale, de 14 Mm³. Le remplissage de cette retenue à partir du barrage Mohammed V a confirmé, par une deuxième méthode, la capacité, donc le volume de vase déposé dans la retenue depuis sa mise en service.

e) Extrapolation de la courbe de dégradation

Cette méthode a été largement utilisée par les Ingénieurs Conseils pour déterminer l'envasement, donc la tranche morte. Mais actuellement au Maroc, des données relativement nombreuses permettent d'appliquer les relations suivantes, en vue de connaître l'envasement d'un barrage préalablement à sa construction.

Données

L'étude suivante revêt une importance particulière à plus d'un égard:

- D'abord elle fait le point sur les connaissances actuelles des transports solides et de l'envasement des barrages au Maroc. Les données récentes sur lesquelles se base cette analyse, ont permis de baser l'expertise sur un échantillonnage relativement élevé et représentatif (bien réparti à travers tout le territoire), et obtenu à partir des deux sources suivantes:

- Mesures de turbidité dans les stations hydrométriques (15 stations choisies).
- Mesures d'envasement des barrages (23 barrages).

Soit, au total, 38 valeurs, comportant chacune : la surface du bassin versant, la lame d'eau écoulée moyenne annuelle et la dégradation spécifique moyenne annuelle.

- Le deuxième résultat pratique et positif de cette étude, est l'éventail important des différentes formations lithologiques des bassins versants à l'amont des barrages. Cette variété des formations, nous a permis d'établir des relations entre la dégradation, la surface des bassins versants et la lame d'eau annuelle. C'est ainsi que des lois de dégradation ont été formulées séparément pour les 3 formations principales:

I	J	K
marnes	calcaires	grès
schistes	marno-calcaires	marno-grès
micaschistes	shales-calcaires	quartzites
limons		granites
shales		pélites
flysch		

- Ainsi ont été différenciées trois formations, chacune étant composée de matériaux présentant une certaine analogie du point de vue de l'érodabilité. L'érosion, au vu des données, est d'ailleurs nettement décroissante en passant du groupe I au groupe K.

L'application pratique des formules établies dans cette étude intéresse un nombre important de départements ministériels:

L'Agriculture, les Eaux et Forêts, l'Intérieur (envasement des lacs collinaires), les Mines (la géologie dominante et la nature lithologique des bassins versants) les Mécaniciens du sol (l'hydrodynamique de la sédimentation) (Faculté des Sciences, Universités, labos..), l'Energie (attaque des pales de turbine etc...), les Routes (glissement de chaussées dans le Rif et Pre Rif, les Ports (alluvionnement et dragage des ports), l'Eau potable (eutrophisation des retenues) etc. Les divers utilisateurs des départements mentionnés appliqueront les relations suivantes en vue de connaître, préalablement à la construction d'un grand barrage ou des lacs collinaires, l'envasement de la retenue considérée en se basant sur les données suivantes:

- surface du bassin versant,
- lame d'eau écoulée moyenne annuelle,
- lithologie dominante du bassin versant.

Résultats

A - Envasement des barrages du Maroc

Le tableau 1 indique, pour les 16 barrages, la hauteur au-dessus de thalweg, la capacité initiale C, la superficie du bassin versant S, l'envasement moyen annuel (Mm³), la dégradation spécifique moyenne annuelle (tkm⁻²) en prenant une densité moyenne de 1,2 tm³ pour les matériaux et un pourcentage de ces derniers évacués à l'aval par la vidange de fond ou les évacuateurs de crues, et les rapports:

$$r_1 = \frac{\text{Envasement}}{\text{capacité initiale}} \%$$

$$r_2 = \frac{\text{Envasement annuel}}{\text{Apport annuel}} \%$$

La valeur de la dégradation annuelle obtenue (voir tableau No.1), permet de classer les régions du Maroc par ordre d'érodabilité décroissante, comme suit:

- Les régions du Bas-Rif central et occidental sur substrats peu cohérents.
- Les régions du Moyen-Atlas et du Haut-Atlas sur substrats peu résistants.
- Les régions de la dépression Rommani Maaziz (Bou Regreg), de l'oued Issen sur roches résistantes.
- Les régions sur roches cohérentes du Moyen-Atlas et du Haut-Atlas, principalement sur les versants atlantiques.
- Les régions de: Sans, basse Moulouya, Moyen et Haut-Atlas.
- Les régions de: Anda, Doukkala, Tensift.
- Les régions: pré-sahariennes et sahariennes.

B - Envasement total actuel de toutes les retenues et prévisions jusqu'à l'an 2000.

Remarques générales

Pour les 16 grands barrages du Maroc, (voir tableau No.1), dont la connaissance du taux d'alluvionnement moyen annuel (depuis leur mise en service) est, en général, bien connue par les méthodes bathymétriques, turbidimétriques, photogrammétrie aérienne, etc... l'envasement total moyen annuel est de 47,8 Mm³ soit 0.53 pourcent de la capacité totale actuelle qui est de 9 032 Mm³ (en prenant pour le barrage Idriss 1er une capacité de 1 217 Mm³ situation en phase 2).

Pour les 31 retenues totalisant une capacité totale actuelle de 9,6 Mm³, l'envasement total moyen annuel serait de 50 Mm³ adoptant le même pourcentage que précédemment. Il faut bien remarquer que ce chiffre de 50 Mm³ est une valeur moyenne interannuelle qu'il faudrait vérifier après chaque crue importante des oueds à l'amont des barrages.

ENVAISEMENT DE BARRAGES DU MAROC

BARRAGES	Date de mise en service	Hauteur (m)	Capacité initiale Mm ³	Superficie du bassin versant (km ²)	Envasement moyen annuel (Mm ³)	Dégradation spécifique annuelle (km ²)	$r_1 = \frac{E}{C}$ %	Apport moyen annuel (Mm ³)	$r_2 = \frac{E}{A}$ %	$r_3 = \frac{E}{A}$ %	R
M.B. Abdelkrim	1981	26,3	43	780	2,7*	5 900	6,3	80	3,37	0,54	53
Ibn Batoute	1977	34,5	43,6	187	0,49	3 900	0,9	65	0,75	0,67	58
Nakhla	1961	46	13	107	0,12	1 680	0,9	68	0,19	0,21	31
EI Makhazine	1979	66,5	789	1 820	1,8 x	1 420	0,2	829	0,22	0,95	67
Moulay Youssef	1970	100	198	1 441	1,4	1 400	0,7	386	0,42	0,59	55
Lalla Taberkoust	1935	71	34,4	1 707	1	850	2,9	165	0,61	0,21	31
Idriss ler	1973	72	1 217	3 680	2	780	0,2	577	0,35	2,11	82
Bin El Ouidane	1953	132	1 484	6 400	3,3	740	0,2	1 127	0,29	1,32	73
Hassan Eddakhi	1971	85	369	4 400	1,75	570	0,5	147	1,19	2,51	84
Mansoun Eddahbi	1972	70	567	15 000	4,7	450	0,8	400	1,17	1,42	75
Al Massira	1979	82	2 724	28 500	9	450	0,3	2 954	0,80	0,92	60
EI Kansera	1935	68	330	4 540	1,4	440	0,4	372	0,38	0,89	65
Mohamed V	1967	64	725	49 920	14,5	420	2	768	1,89	0,94	66
Yousef Ben Tachline	1973	85	310	3 784	1,1	420	0,4	122	0,90	2,54	85
S. Mohammed Ben Abdellah	1974	98	493	9 800	2,5	370	0,5	836	0,30	0,59	55
Tanzaourt	1981	94	216,3	1 300	0,2	200	0,1	87	0,23	2,49	84

* L'alluvionnement de ce barrage, déterminé par bathymétrie en 1985, pour la période de 1981 (date de mise en service) à 1985, est de 4,9 Mm³ fournissant un envasement annuel de 1,2 Mm³; ce taux relativement faible résulte de la sécheresse de 1980-1985.

x L'alluvionnement de ce barrage, déterminé par bathymétrie en 1985, pour la période de mai 1979 (date de mise en service) à 1985, est de 6,1 Mm³, fournissant un envasement annuel de 1,0; ce taux relativement faible est attribuable à la sécheresse de 1980-1985.

- Un grand nombre de levés de dépôts, a été réalisé dans les retenues du Maroc.

Le tableau No.1 indique l'importance de l'envasement des retenues au Maroc ainsi que les fortes dégradations du substratum des bassins versants amont.

En prenant un taux moyen annuel de 50 Mm³ et en supposant que l'érosion persiste à sa valeur actuelle, d'ici l'an 2000 il y aura un envasement total 50 Mm³ x 16 soit 800 Mm³ ce qui correspond à 9 pourcent de la capacité actuelle.

- L'envasement total depuis la mise en service des 16 plus grands barrages du Maroc, dont les plus anciens ont été réalisés en 1935, (il y a 50 ans comme El Kansera, Lalla Tekerkoust), et les derniers en 1981, est de 593 Mm³, ce qui représente 6 pourcent de la capacité totale initiale.

- Pour un barrage donné, le rapport montre que l'envasement total depuis sa mise en service et sa capacité initiale, varie entre 0,7 pourcent (Tamzaourt) et 71 pourcent (Lalla Takerkoust).

Ce rapport dépend de l'ancienneté du barrage et du taux d'envasement moyen annuel.

- L'apport liquide moyen annuel aux 16 retenues, est de 9,09 Gm³; leur envasement moyen annuel étant de 47,8 Mm³, le rapport moyen entre l'envasement moyen annuel et l'apport liquide moyen annuel (ayant servi à véhiculer cet apport solide), est de 0,5 pourcent.

Le rapport entre l'apport solide annuel et l'apport liquide, varie comme suit:

$$\frac{0,19}{(\text{NAKHLA})} < r_2 < \frac{3,37}{(\text{NEKOR})}$$

Ainsi pour le Nekor, il faudrait en moyenne, 30 m³ d'eau pour amener 1m³ de vase au barrage Mohamed Ben Abdelkrim Al Khattabi, alors qu'il faudrait, en moyenne, un apport d'eau de 530 m³ pour amener 1m³ de vase au barrage Nakhla. Ce rapport dépend des conditions d'écoulement et de la nature lithologique dominante du bassin versant à l'amont du barrage considéré.

D'autre part, nous remarquons aussi que la dégradation la plus élevée est celle du bassin versant du Nekor ($D = 5\,900 \text{ tkm}^{-2} \text{ an}^{-1}$) correspondant à un envasement annuel de 2,7 Mm³. Cette valeur a été obtenue par deux méthodes: l'analyse jusqu'à 1982 des transports solides à la station hydrométrique de Tamellaht, et l'analyse de la sédimentation des seuils réalisés sur l'oued hekrane, Sidi Aissa... du bassin versant. La formation lithologique est de type I. La valeur de l'envasement observée en 1985 est de 1,2 Mm³ (période de sécheresse).

Le barrage marocain qui présente l'envasement annuel le plus élevé est celui de Mohamed V sur l'oued Moulouya: envasement moyen annuel 14,5 Mm³ pour une surface du bassin versant de 49 920 km². La dégradation spécifique moyenne annuelle correspondante est: $D = 420 \text{ tkm}^{-2}$

C - Relations obtenues

Les relations suivantes permettent de prévoir:

C1 - Relations obtenues entre la dégradation spécifique annuelle et la surface du bassin versant S pour différents types de formations lithologiques dominantes des bassins versants (voir graphique No.2)

- Pour les 16 barrages ayant fait l'objet d'études d'envasement (16 valeurs):

$$D = 14.10^3 S^{-0,363} \quad (\text{Droite A})$$

- Toutes formations lithologiques, (38 valeurs: 23 barrages + 15 mesures de turbidités):

$$D = 3,9 \cdot 10^3 S^{-0,203} \quad (\text{Droite B})$$

- Formations calcaires (11 valeurs), type J:

$$D = 7.10^3 S^{-0,012} \quad (\text{Droite C})$$

- Formations schisteuses et marno-schisteuses, type I:

$$D = 17.10^3 S^{-0,329} \quad (\text{Droite D})$$

- Régions à faibles érosion, (23 valeurs) type K:

$$D = 5.10^3 S^{-0,026} \quad (\text{Droite E})$$

C2 - Relations obtenues entre la dégradation spécifique moyenne annuelle D et la lame d'eau écoulee moyenne annuelle pour diverses types de formations lithologiques: (voir graphique No.3)

- Pour toutes formations lithologiques (38 valeurs dont 23 barrages et 15 mesures de turbidités), on a:

$$D = 21 L^{0,7299} \quad (\text{Courbe A'})$$

- Formations calcaires, type J:

$$D = 70 L^{0,434} \quad (\text{Courbe B'})$$

- Formations schisteuses et marno-schisteuses, type I:

$$D = 23 L^{0,449} \quad (\text{Courbe C})$$

- Régions à forte érosion (15 valeurs):

$$D = 1,5 \cdot 10^3 L^{0,070} \quad (\text{Courbe D'})$$

- Régions à faible érosion, type K:

$$D = 90 L^{0,347} \quad (\text{Courbe E'})$$

- 16 barrages ayant fait l'objet de mesure de sédimentation:

$$D = 62,5 L^{0,545} \quad (\text{Courbe F'})$$

C3 - Corrélations multiples entre la dégradation spécifique moyenne annuelle D (tkm^{-2}), la surface du bassin versant S (km^2), et la lame d'eau écoulée moyenne annuelle L (mm) au Maroc.

- Toutes formations lithologiques (38 valeurs):

$$D = 10^{1,753} \quad S = -0,075 \quad L = 0,628$$

- Forte érosion (15 valeurs):

$$D = 10^{2,965} \quad S = -0,053 \quad L = 0,093$$

- Marnes et marno-schistes (17 valeurs):

$$D = 10^{1,748} \quad S = -0,082 \quad L = 0,712$$

- 16 barrages (16 valeurs):

$$D = 10^{3,425} \quad S = -0,174 \quad L = 0,072$$

Toutes ces relations (représentées graphiquement ci-après) sont largement utilisées pour prévoir le taux d'envasement des barrages avant leur construction.

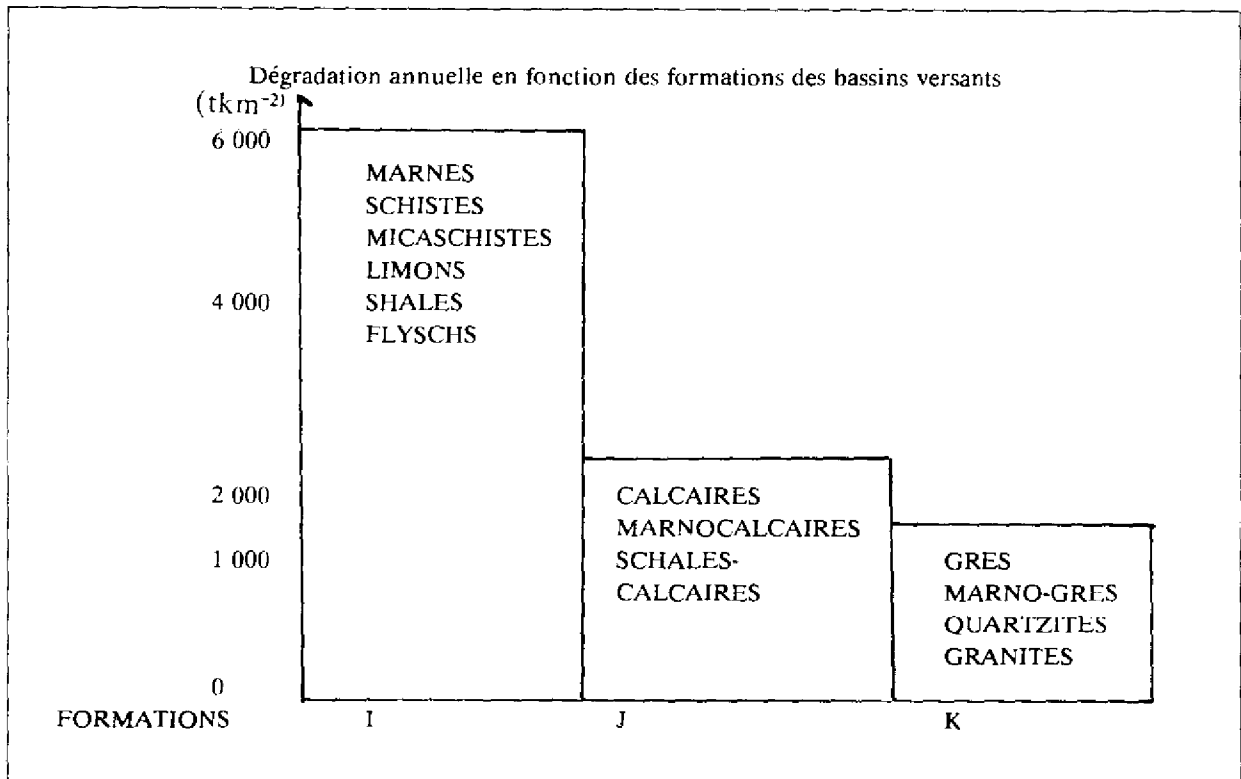
Il est à signaler que les formules ainsi obtenues, sont toutes basées sur les observations obtenues par les méthodes précitées (bathymétrie, photographie aérienne, turbidimétrie etc..) ainsi que sur les caractéristiques: surfaces des bassins versants, apports liquides et lames d'eau aux barrages considérés, d'où l'intérêt particulier de leur validité.

Autres relations obtenues

1) Coefficient d'agressivité climatique

Les autres méthodes ayant servi à la détermination de l'envasement sont les suivantes:

- Au départ, ne disposant pas suffisamment de données de turbidité et d'envasement, la formule de Fournier a été utilisée pour la détermination de la vitesse d'érosion et l'estimation du volume des sédiments arrachés chaque année au bassin versant:



$$D = 6,14 C - 49,78 \quad (\text{tkm}^{-2})$$

où C est un coefficient d'agressivité climatique donné par:

$$c = \frac{p'}{\bar{P}}$$

où p' est la précipitation du mois le plus humide, et \bar{P} la précipitation moyenne annuelle.

Cette formule a évolué vers d'autres relations plus sophistiquées.

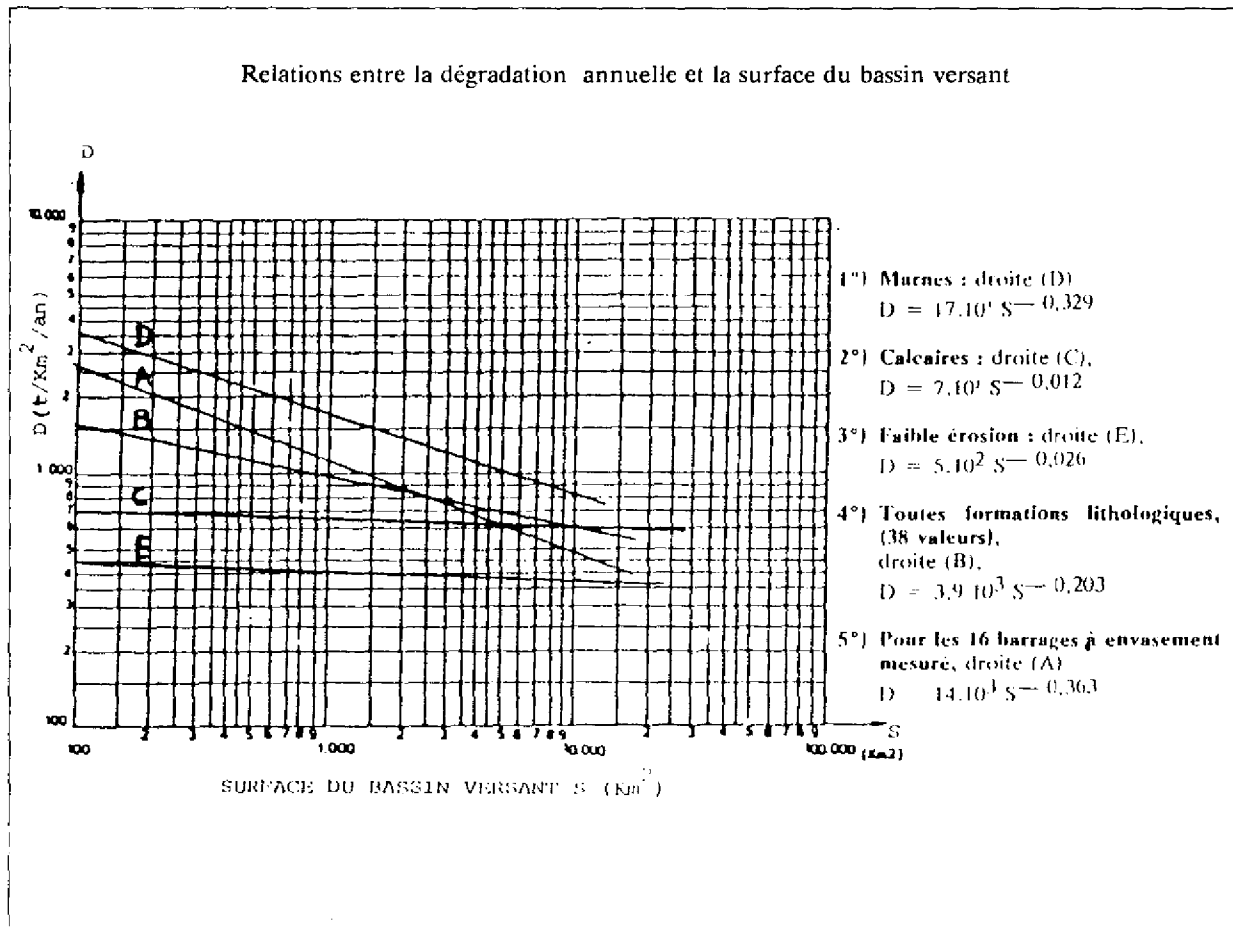
2) Formule de la FAO (Projet Erosion)

La relation suivante, établie à partir de l'observations de 112 pluviomètres, a été utilisée:

$$R = 1,73 \times 10 \left(1,5 \log \sum_{i=1}^{12} \frac{p'}{\bar{P}} + 0,8188 \right)$$

où: p' est la précipitation du mois le plus humide (mm) et \bar{P} est la précipitation moyenne annuelle (mm)

3) Corrélation entre les apports solides et les apports liquides annuels



Nous avons vu que la corrélation entre apports solides (A_s) et liquide (A_l) annuels, dans les stations hydrométriques, à l'amont des barrages, constituait aussi un moyen de connaître l'envasement d'un barrage.

Exemples: la régression obtenue l'oued Ouergha pour le futur barrage de M'Jara:

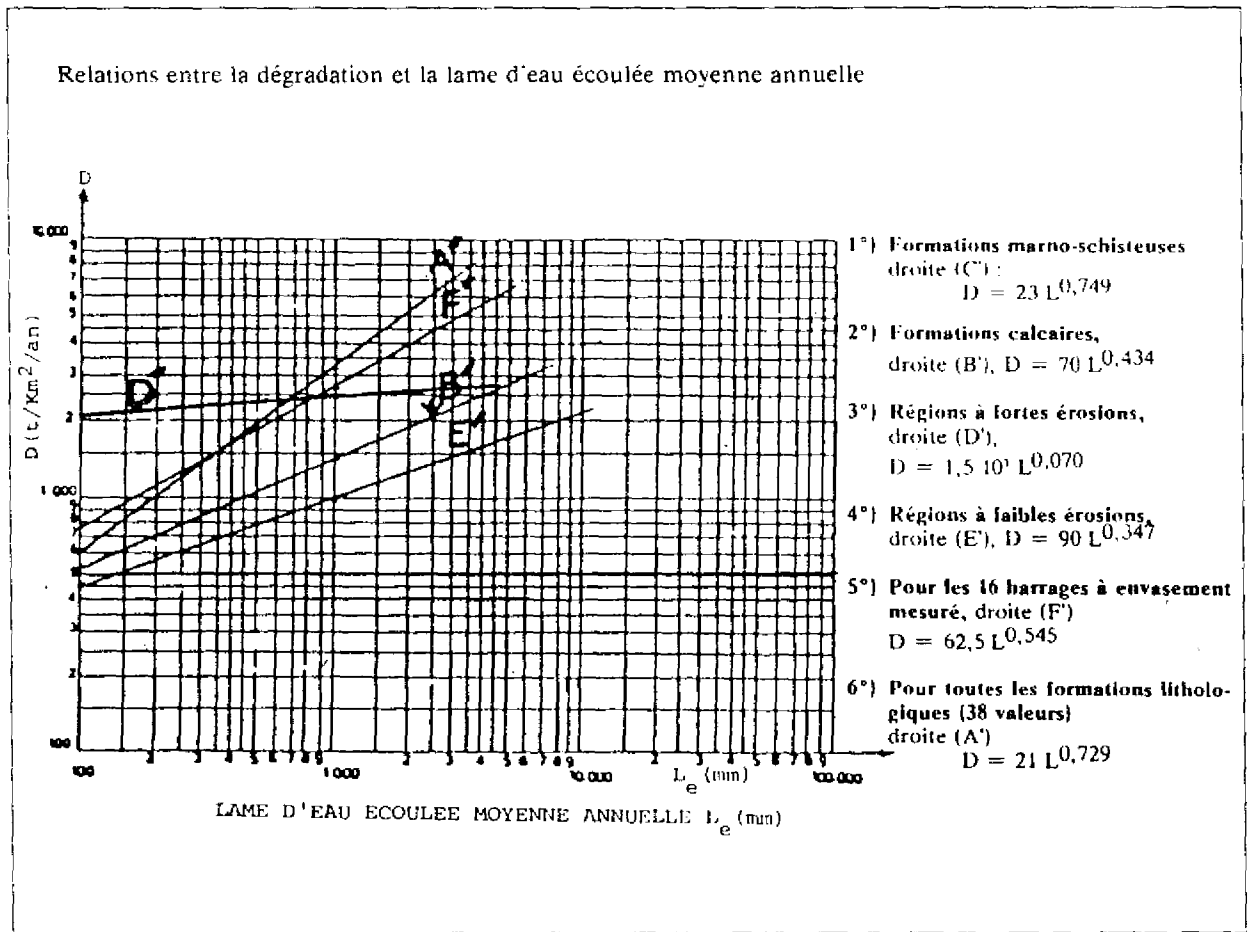
$$A_l = 690 A_s^{0,58}$$

permet d'évaluer un envasement moyen annuel à M'Jara de 12 Mm^3 .

Cette corrélation a été utilisée pour déterminer les transports solides aux stations hydrométriques de Khénifra, Dechra El Oued, Melg El Ouidane, Dar Es Soltane, Tamellaht, etc.

4) Relation de Brume

Au départ, la courbe de Brume donnant $D = p(S)$, a été utilisée pour estimer l'envasement en l'absence de données. D'autre part, Brume (1955), a défini le pourcentage des sédiments piégés (R en %) dans une retenue par:



$$R = 100 \left[1 - \frac{I}{I + 2, I \left(\frac{C}{A} \right)} \right]$$

où $\frac{C}{A}$ est le rapport entre la capacité de la retenue C et l'apport A. Le tableau No.1 indique les valeurs de R au Maroc.

5) Formule de Miller

- Le poids volumique des dépôts peut aussi être déterminé par la formule de Miller:

$$Y = W' + 0,4343 \left[K \frac{T}{T-1} (\log T - 1) \right]$$

où W' est le poids volumique apparent, K est une constante de consolidation, T est la période de consolidation.

6) Relation entre l'envasement, la surface du bassin versant et le rapport entre la capacité et l'apport liquide.

La régression multiple entre l'envasement moyen annuel E (Mm³), la surface du bassin versant S (km²) et le rapport (C/A) conduit pour les 16 barrages du tableau No.1 à la relation:

$$E = 10^{-2.228} S^{0.699} \left(\frac{C}{A}\right)^{-0.259}$$

(obtenue en 1984)

avec un coefficient de régression multiple de 0,75.

7) Utilisation des techniques nucléaires

L'utilisation des techniques nucléaires par traceurs radioactifs et jauges nucléaires de turbidités (association d'une source radioactive émettrice et d'un détecteur de radioactivité), en vue de connaître la vitesse de sédimentation des particules en suspension et, par suite l'envasement, est actuellement à l'étude au Maroc.

D - Remarques

En vue d'affiner la connaissance de l'envasement des retenues des barrages du Maroc, il y aurait lieu de prendre en considération les recommandations suivantes:

- Augmenter la fréquence des relevés d'envasement des barrages existants au vu de l'importance de leurs taux annuels d'alluvionnement (la fréquence sera d'autant plus élevée que la sédimentation est importante et que la capacité est réduite). Une fréquence de 2 ans et même annuelle de mesures d'atterrissements dans les retenues (par bathymétrie, topographie, etc.) est souhaitable; il est à remarquer que ces travaux doivent être réalisés juste après une crue importante, afin d'établir la nouvelle courbe de capacité en fonction de la hauteur.

- Procéder à l'analyse de tous les facteurs intervenant dans le phénomène de l'érosion: couvert végétal, superficies cultivées, pluviométrie maximale de 24 heures, et autres intervalles, apports de crues, pentes, etc. Une série de formules basées sur ces données reste à établir.

L'analyse détaillée de la suspension et du charriage reste à faire; à cet égard, des mesures de concentrations sont à réaliser dans les oueds du Maroc et de leurs affluents, en vue de parfaire la connaissance de ces transports et de leur évolution dans le temps, par les méthodes connues du type: Du Boys, Meyer-Peter, Schoklitsch, Shields, Yalin, Einstein ou Lane, pour le charriage.

En vue de limiter et réduire l'envasement des barrages afin d'assurer une plus grande perennité et une meilleure mobilisation des ressources en eaux, l'analyse des problèmes de l'érosion à l'échelle nationale a débouché principalement sur l'établissement des schémas directeurs d'interventions anti-érosives pour les bassins versants suivants:

Loukkos	180 000 ha	1976
Nekkor	78 000 ha	1977
Tléta	18 000 ha	1978
Tessaout	154 000 ha	1977
N'Fis	170 000 ha	1981
l'Inaouène	150 000 ha	1983
Issen	130 000 ha	
Azilal		

Chacun des schémas-directeurs a comporté les analyses suivantes:

- le milieu physique et les unités physiographiques
- les facteurs de l'érosion
- la situation socio-économique
- l'évaluation des besoins en moyens de lutte anti-érosive, de leur programme d'exécution et de leur coût.

Les traitements anti-érosifs suivants ont été planifiés: a) Mesures de lutte contre l'érosion à appliquer sur le réseau hydrographique (traitement mécanique).

b) Mesures de conservation des sols à appliquer à des terres affectées aux cultures annuelles (traitement biologiques).

c) Mesures de conservation des sols à appliquer à des terres affectées partiellement ou totalement à des cultures fruitières.

d) Mesures de conservation des sols à appliquer à des terres affectées partiellement ou totalement à la production fourragère.

e) Mesures de conservation des sols à appliquer à des terres avec objectif principal de la protection du reboisement.

Les traitements mécaniques des bassins versants à court terme: (protection des berges et des terrasses alluviales, construction de seuils et d'épis guide-eau aux confluences, d'un seuil au Nekor, etc.), et les interventions biologiques à moyen et long terme sont les aménagements déterminants, réduisant l'érosion à la source, donc le transport solide et l'envasement des retenues. En plus d'une politique adéquate de gestion des grands ouvrages hydrauliques, l'implantation d'un certain nombre de bassins expérimentaux (pour la quantification de l'érosion), est, par ailleurs, recommandée.

Conclusion

Cette étude présente les résultats de l'analyse de l'érosion et de la dégradation spécifique moyenne annuelle des bassins versants du Maroc, pour les diverses formations géologiques.

- Elle permet d'abord, au vu de l'éventail des données de définir les ordres de grandeur et les limites des dégradations mesurées et observées par diverses méthodes.

- D'autre part, à partir des diverses relations mentionnées dans cette étude, on peut, préalablement, connaître la dégradation spécifique moyenne annuelle (et par conséquent l'envasement moyen annuel) en fonction de la surface du bassin versant, la lame d'eau écoulée moyenne annuelle et la lithologie dominante du bassin versant. Les valeurs des taux d'atterrissements obtenus par cette méthode ont été comparées avec celles obtenues par d'autres méthodes et il s'est avéré qu'elles sont applicables pour déterminer l'envasement d'une future retenue.

Cette étude sera complétée et actualisée dès l'acquisition de données de turbidité actualisées aux stations hydrométriques et d'autres valeurs d'envasement en cours d'observation. Il faudra généraliser les mesures d'envasement, par travaux bathymétriques,

des retenues n'ayant pas fait l'objet de tels travaux, et d'augmenter la fréquence des mesures d'ailleurs. Les mesures turbidimétriques, aux stations hydrologiques, sont à multiplier et à généraliser au moins aux stations principales se trouvant à l'amont de barrages.

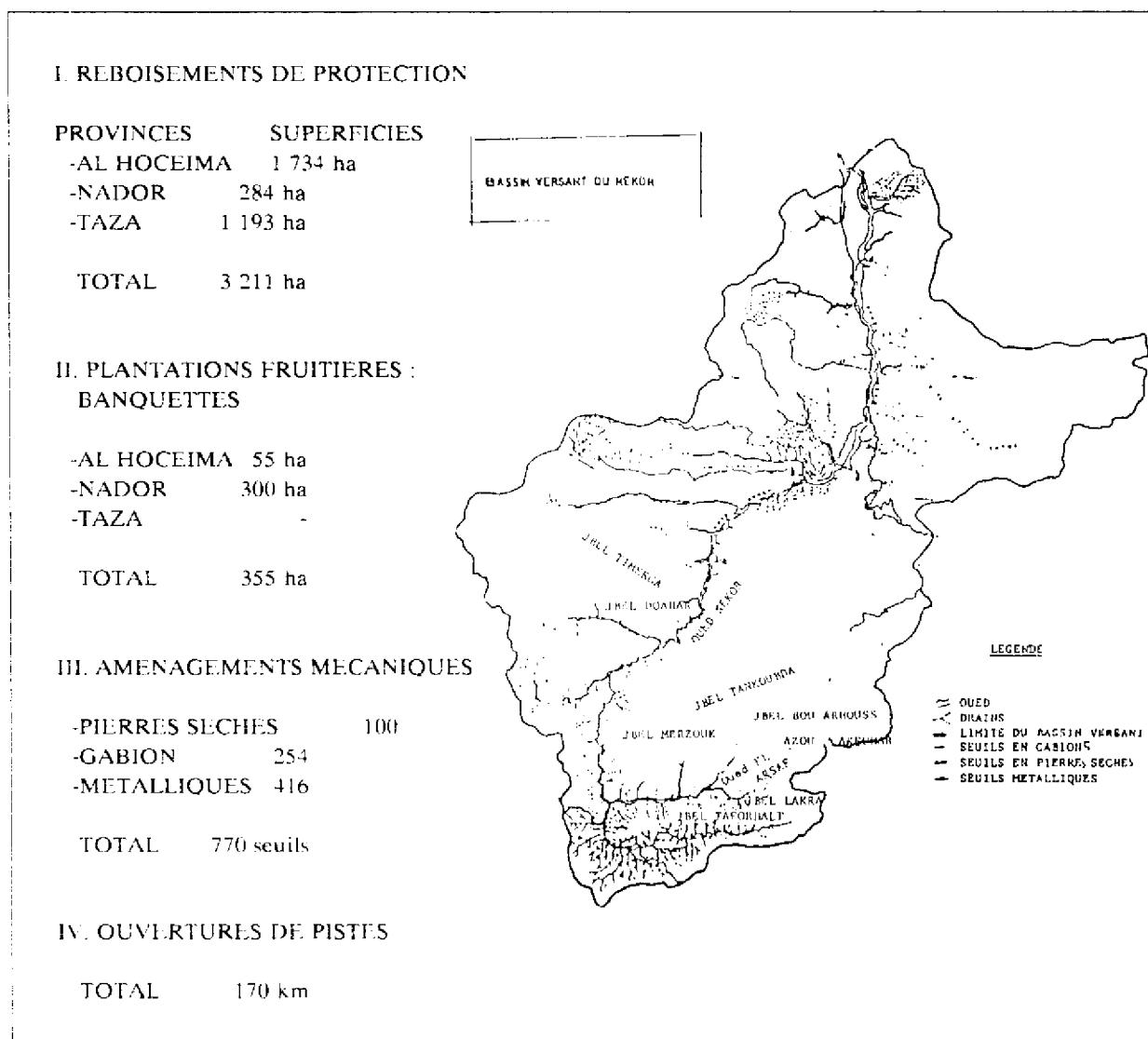
Cette étude synoptique de l'érosion des bassins versants présentant des caractéristiques lithologiques similaires, pourrait être affinée, si on disposait d'autres facteurs conditionnant l'érosion à savoir: les superficies intéressées par les divers types de végétation, les pentes avec leur fréquence maximale, etc.

L'un des paramètres rentrant dans les études de régularisation (donc de dimensionnement des futurs barrages) étant l'envasement, il y a lieu d'insister sur l'importance que requiert une telle étude (ainsi que de son actualisation continue), en vue d'affiner la connaissance de la sédimentation dans les lacs réservoirs marocains.

On trouvera en annexe un exemple d'interventions mécaniques et biologiques dans le bassin versant du Nekor (situé au Nord-Est du Maroc) et réalisées par l'Administration de l'Hydraulique et la Direction des Eaux et Forêts (Division de la défense et de la restauration des sols).

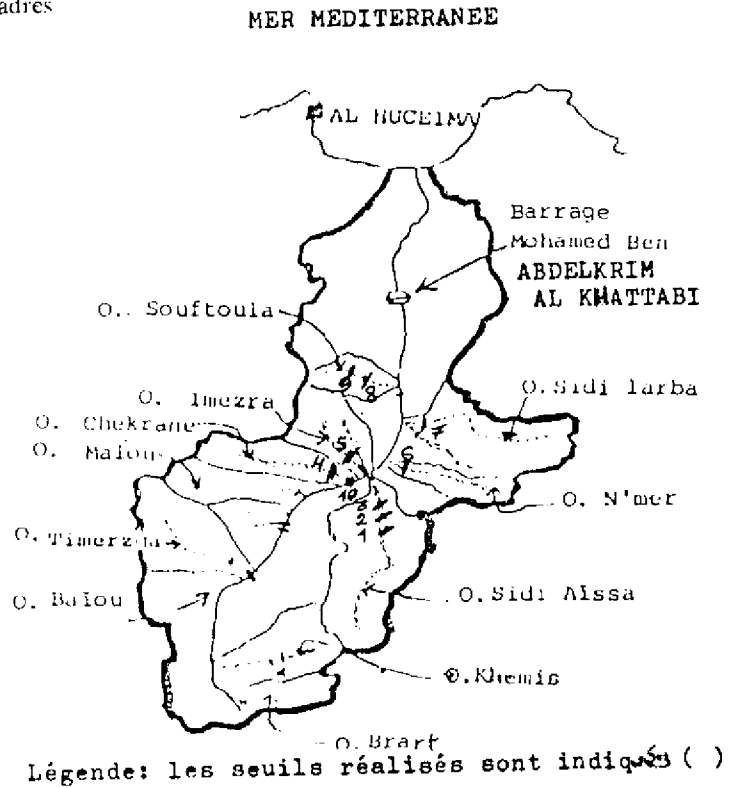
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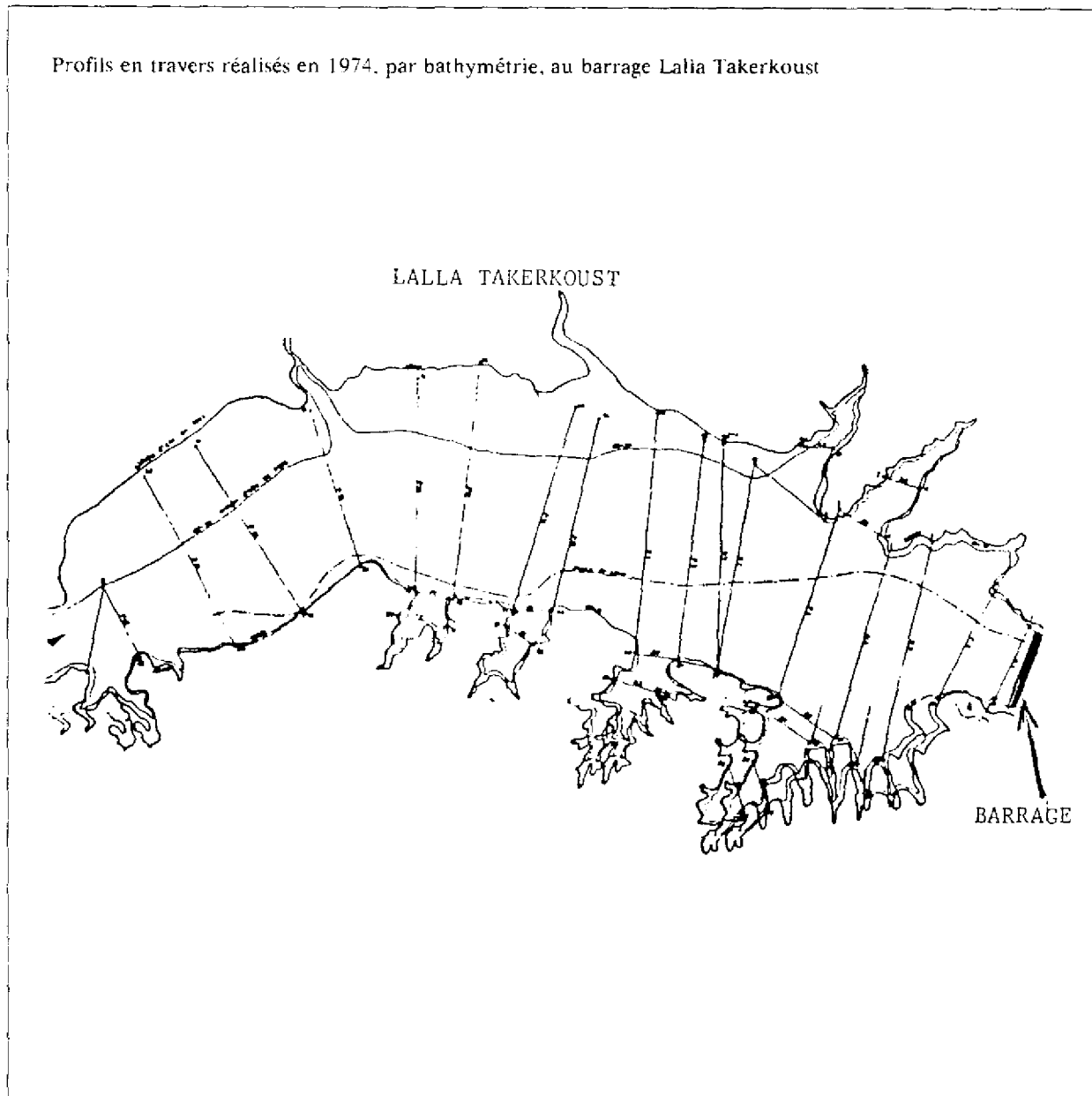
BILAN DES REALISATION ANTI-EROSIVES (effectuées de 1977 à 1983) dans le bassin versant de l'oued Nekor par le Ministère d'Agriculture et de la Réforme Agraire.



Caractéristiques des seuils de sédimentation réalisés par le Ministère de l'Équipement de la Formation Professionnelle et de la Formation des Cadres

Sous bassins	Superficie (km ²)	Volume des gabions (m ³)	Envase-ment moyen annuel (m ³)
Souftoula (amont)	15.1	7 200	27 000
Souftoula (aval)	15	5 560	18 000
Imezra	22	7 172	45 000
Chekrane	37	9 838	60 000
Sidi Aïssa	91	4 000	288 000
Sidi Aïssa	72	1 476	36 000
Sidi Aïssa	64	1 400	70 000
N'Mer	21	1 600	3 000
Sidi Larba	54	2 300	9 000
TOTAL	38 900	556 000	





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PAPER 32

IMPACT ON THE RIVER BED AND TEMPERATURE REGIME OF A SERIES OF STORAGE RESERVOIRS IN THE MARITZA RIVER BASIN

K. Ivanov and D. Pechinov

In order to meet energy, water supply, irrigation and other needs, a system of 8 large reservoirs and more than 400 small reservoirs has been built between 1957 and 1972 in the Maritza River Basin. (Fig. 1).

Under their influence the streamflow and sediment runoff have changed considerably. Due to the retention of the reservoirs and diversion of water for various purposes (the consumptive losses are considerable), the streamflow in the river basin has decreased to a greater or smaller extent. Because of the influence of the reservoirs, all the bed load and the greater part of the suspended sediments are retained. The variation of the coefficient of suspended sediment and of the water discharge of the Maritza River at the Plovdiv hydrometric station is shown in Fig. 2.

The coefficients are the relation between the mean-annual and mean-multiannual values of the streamflow and of the respective suspended sediment discharge. Fig. 2 shows that the streamflow for the period 1955-1984 has decreased by 30 percent, while the sediment discharge has decreased by 300 percent.

The decrease naturally affects the distribution of the sediment discharge during the year, not only is there a considerable decrease (except in September) but there is an equalization during the different months (Fig. 3).

The index of sediment discharges is expressed as a relation between the sediment discharges for two typical periods: pre-dam (R2) and post-dam (R1), the value $k_i = (R2)/(R1)$ increases from 0,23 to 1,00 (Fig. 3).

It is known that in case of conformity between the transport capacity (determined first of all by the water discharge) and the actual sediment content, no river bed deformations are observed. When this conformity is disturbed, deformations occur mainly in the form of degradation or aggradation of the river bed.

In the case of the Maritza River, an increase of transport capacity is observed due to the decrease of the actual sediment content in the flow, which strives to compensate the deficit of bed material by scouring the river bed. For this reason an intensive degradation of river bed is observed.

It may be noted that in the period before building the series of reservoirs in the middle reach of the Maritza River the bed was in equilibrium, while downstream there had been a tendency for river bed aggradation.

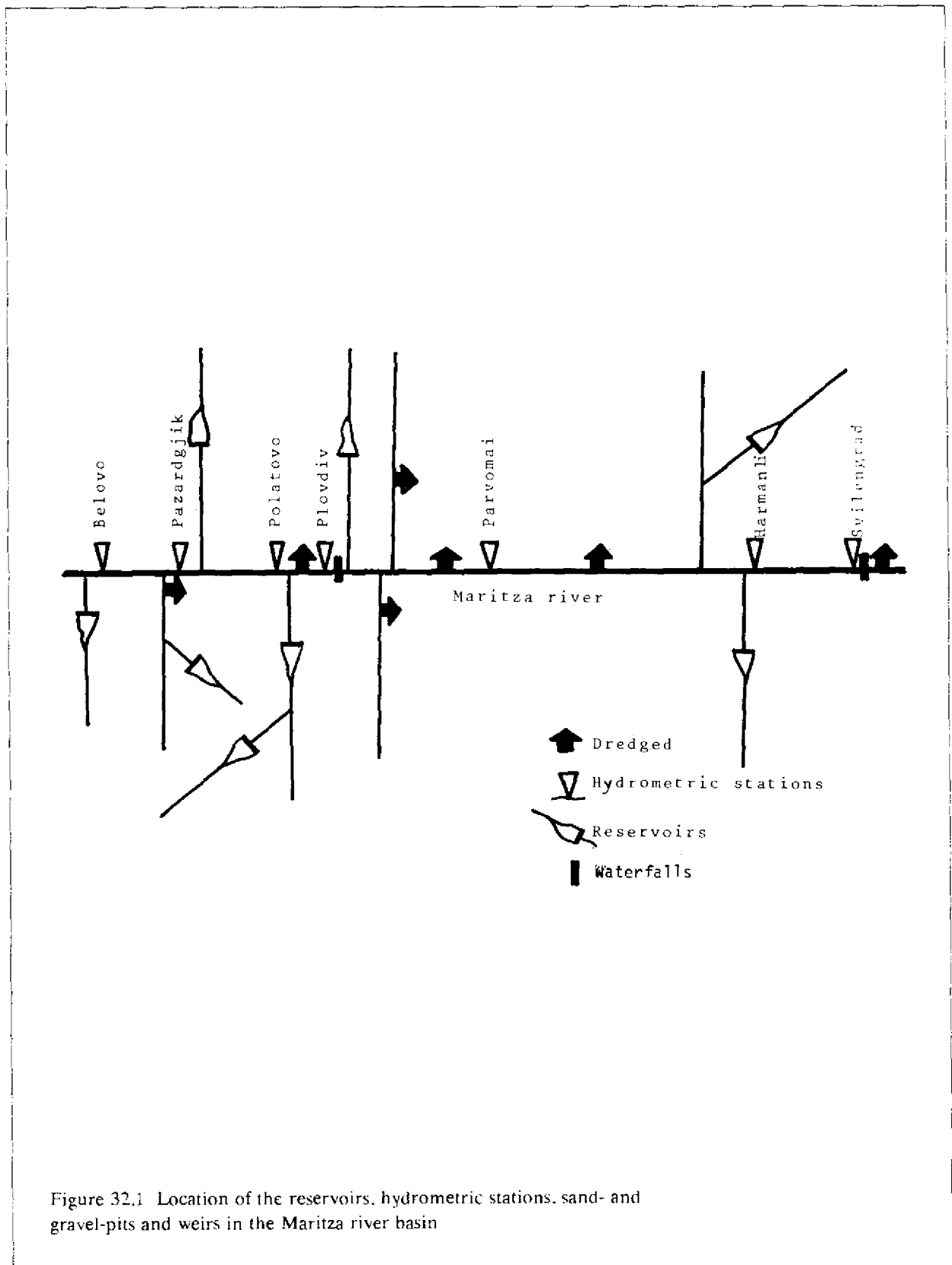


Figure 32.1 Location of the reservoirs, hydrometric stations, sand- and gravel-pits and weirs in the Maritza river basin

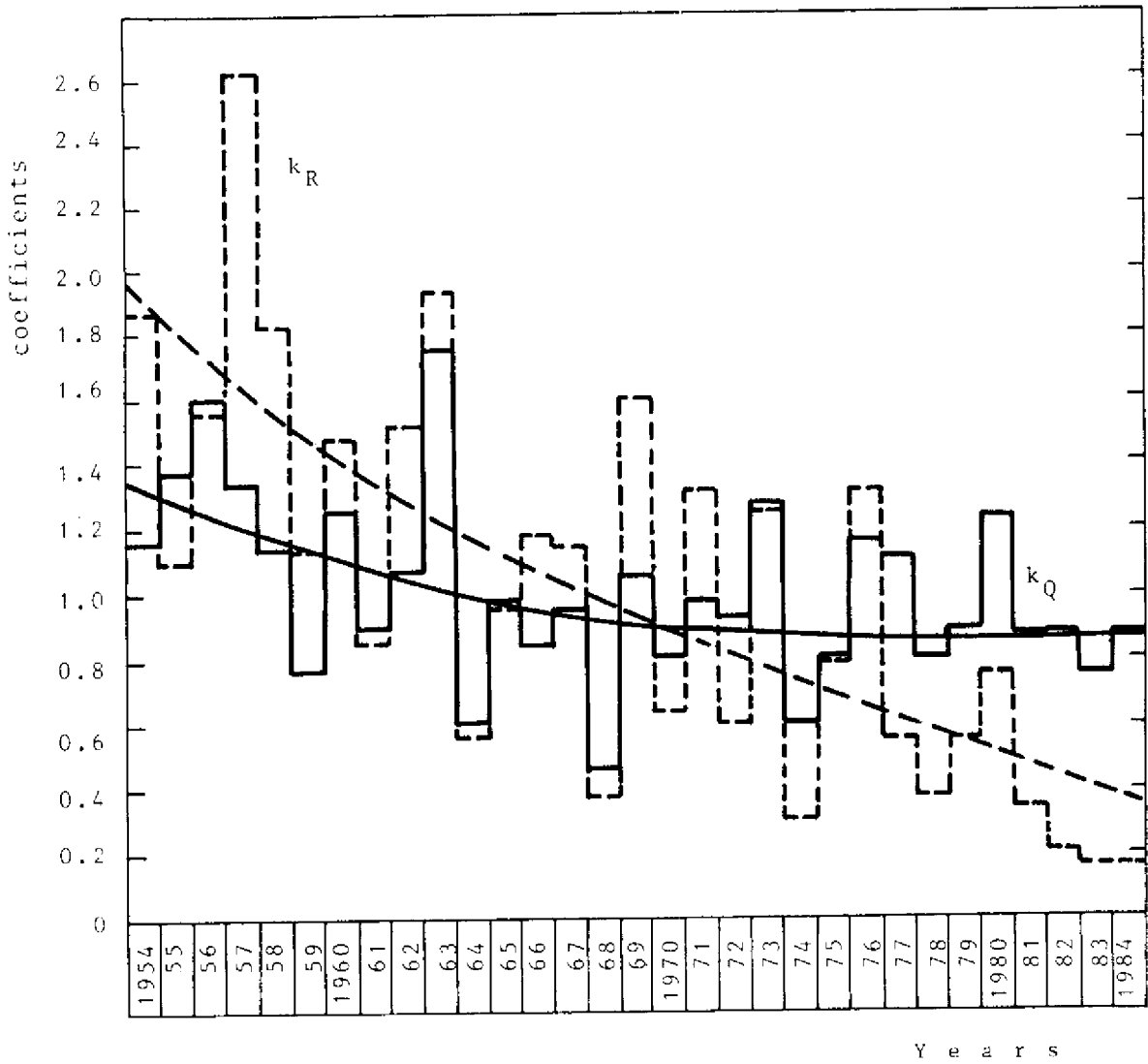


Figure 32.2 Variation of the coefficients of streamflow (k_Q) and sediment discharge (k_R) of the Maritza river at Plovdiv for the period 1954-1984.

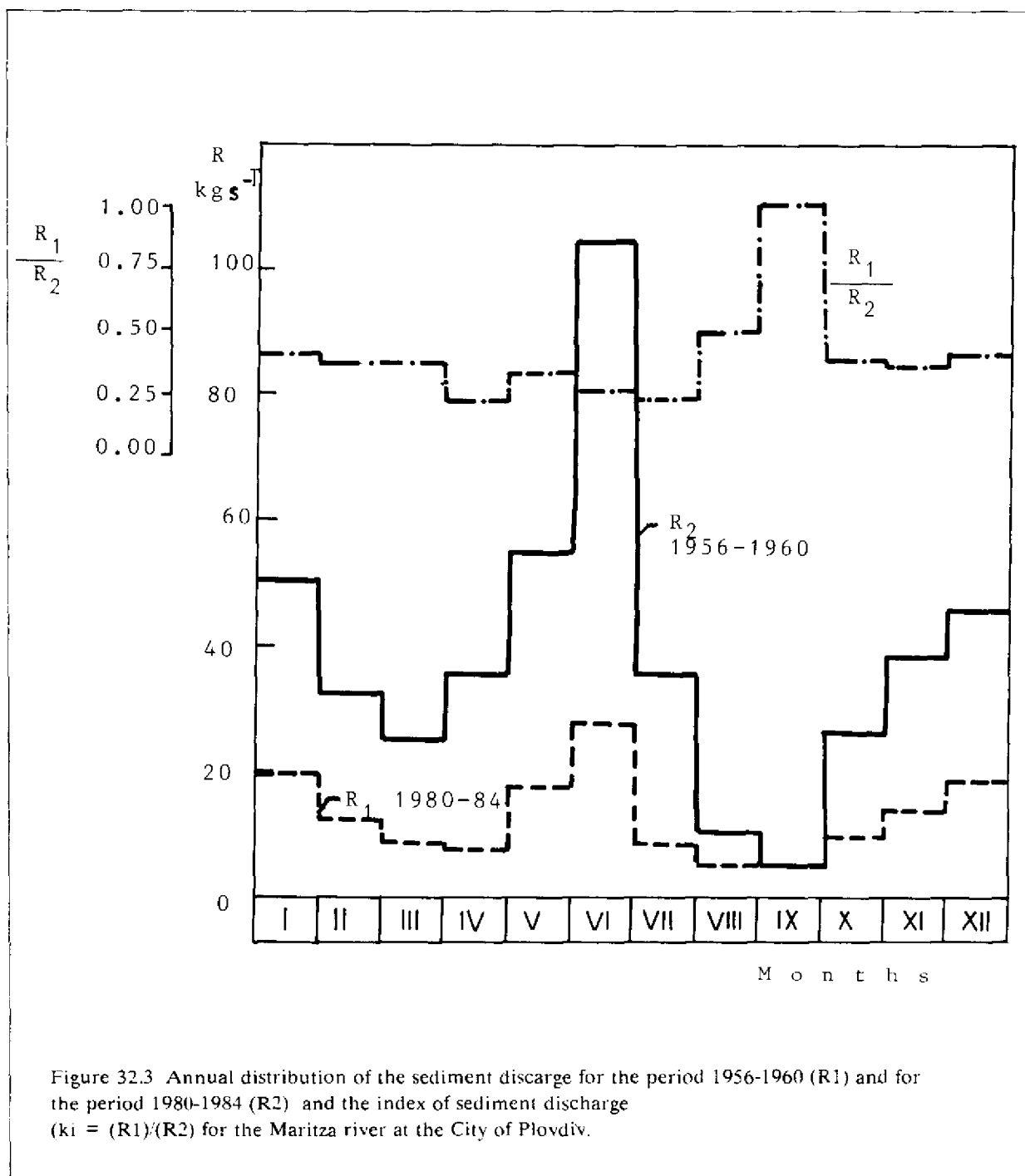


Figure 32.3 Annual distribution of the sediment discharge for the period 1956-1960 (R₁) and for the period 1980-1984 (R₂) and the index of sediment discharge ($k_i = (R_1)/(R_2)$) for the Maritza river at the City of Plovdiv.

The changes of the relation between streamflow and water levels at the hydrometric stations (the relation is calculated every year) illustrates the intensity of river bed degradation. Direct topographic measurements are very labour intensive and do not give good results (Fig. 4). The most significant streamflow is the mean multiannual value.

Fig. 5 shows the trend of change of river bed by means of the water level corresponding to the mean multiannual streamflow for various points along the Maritza River. It may be seen that the river bed at the town of Pazardjik has dropped by 1.90 m during the 18-year period 1955-1973. This represents a mean annual degradation of about 10 cm. At the town of Svilengrad the degradation of the Maritza river bed is 1.30 m for the 7-year period 1972-1979, representing a mean annual degradation of 18 cm.

Dredging of bed load from the river bed, usually for the needs of the building industry (at 7 points), also contributes to the river bed degradation at considerable distances upstream and downstream of the dredging pit. The reason for river bed degradation downstream of the sand and gravel pit is the tendency of river flow to compensate the deficit of bed load deposited in the pit.

The intensive degradation of the Maritza River bed under the influence of the reservoirs and the sand and gravel pits has resulted in the destruction of a number of bridges, culvert syphons, etc. For example, the 100 year-old bridge across the Maritza River in the city of Plovdiv collapsed as did the railway bridge on the Chaperlarska River at the village of Katunitza.

Due to the lowering of the water level in the rivers and the associated fall of groundwater levels in the adjacent areas, a number of water supply systems have been destroyed. Especially susceptible to the quick changes of groundwater level are the perennial plants which cannot adapt their root system to the fall of water levels and dry up.

The rapid development of river bed degradation, destruction or decreased stability of communication, hydrotechnical and other structures as well as negative impacts on the environment, has led to the building of a number of weirs which halt the degradation of the river bed in a river section for a considerable length upstream of the weir, as seen in Fig. 5 at the Pazardjike, Plovdiv and Svilengrad bridges where such weirs have been built. The actual deficit of sediment in the streamflow cannot be overcome by building weirs, so the degradation of the river bed beyond their zone of influence continues.

Between 1947 and 1960 due to the influence of the inflow of comparatively colder waters released by several large high mountain reservoirs, a gradual and considerable decrease of water temperature in the Maritza River began. The quantitative change of temperature is shown on the curves of annual temperature distribution (Fig. 6) where it can be seen that the decrease of the temperature continues throughout the year and that it is comparatively greater in the spring and summer than in the autumn and winter.

A decrease of the water temperature along the main river is observed between Belova and Plovdiv. Downstream of the city of Plovdiv the influence of the cold reservoir waters is entirely compensated for by the warm industrial waters discharged to the river by the towns.

The index of temperature at the Belovo hydrometric station i.e. the difference between river water temperature under natural and disturbed conditions, varies between 1.6|0C in February and 4.4|0C in July.

The damage to the economy and the environment resulting from the increase of river-water temperature due to man's activities is much greater, and, at the present time, more apparent than the damage caused by the decrease of water temperature. Nevertheless, the artificial decrease of water temperature may also lead to some negative consequences. Thus for example, irrigating with cold reservoir waters or with water from aquifers located in

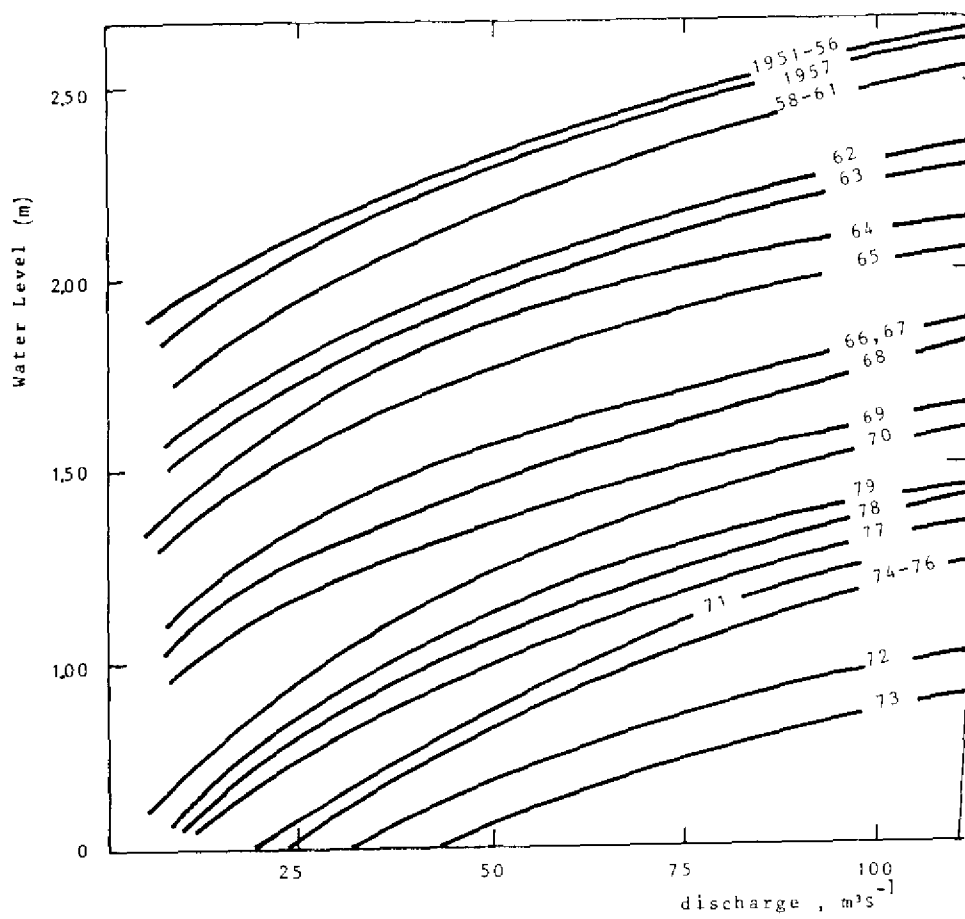


Figure 32.4 Relation between water levels and streamflow for the Maritza river and the town of Pazardjik.

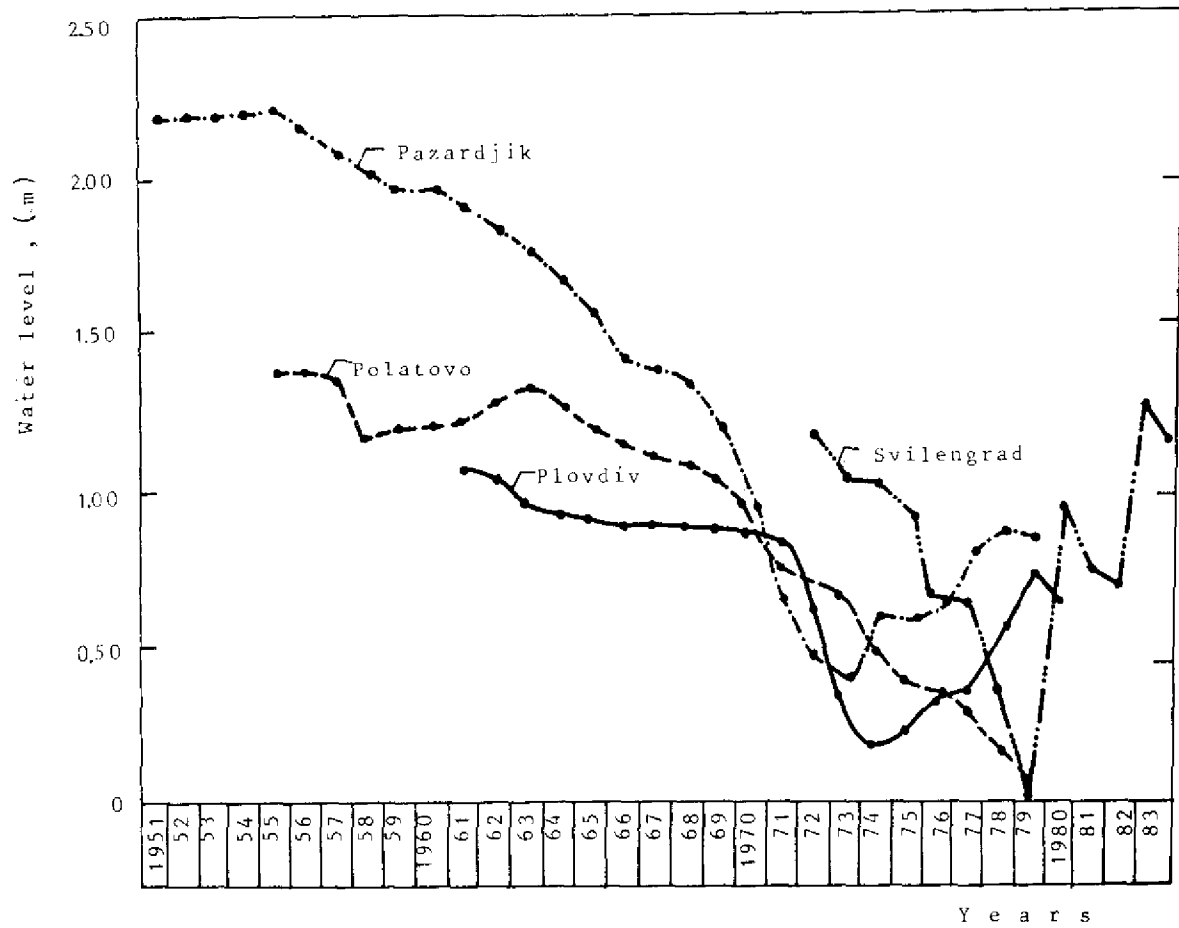
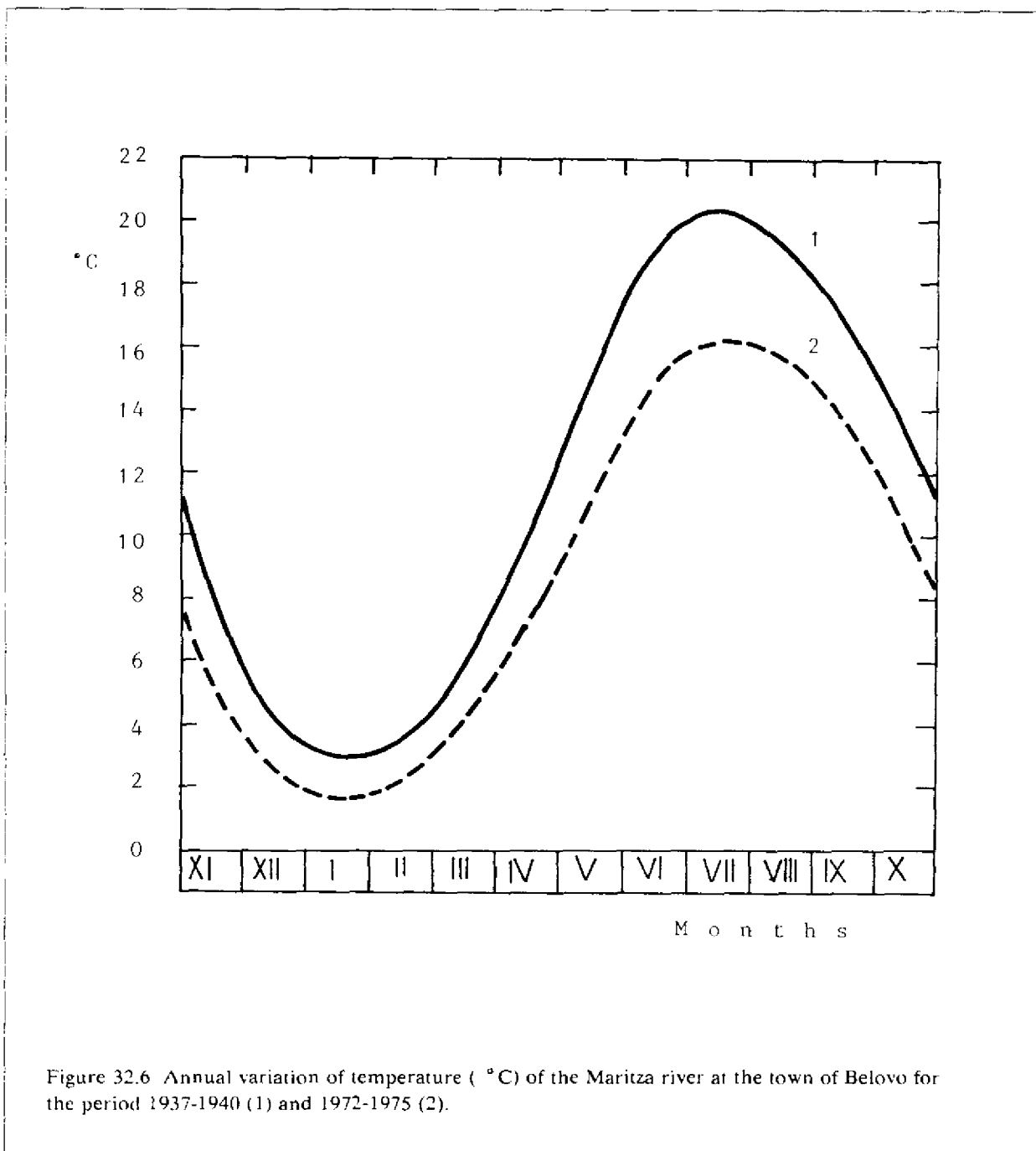


Figure 32.5 Change of water levels corresponding to the mean multi annual streamflow at the hydrometric stations on the Maritza river in the period 1951-1983.



high mountain regions, retards the development of crops in spring and the yields of rice and cotton decrease in autumn. The adaptation of fish to life in colder water is slower and more difficult than vice-versa.

When temperatures are lowered the speed of biochemical oxidation of organic substances is retarded as are the self-purification processes. Drinking water with temperatures below 10°C causes colds and stomach troubles.

PAPER 33

INFLUENCE DE DIFFERENTS TYPES D'AMENAGEMENTS HYDRAULIQUES EMBOITES SUR LES REGIMES HYDROLOGIQUES ET LES POTENTIALITES D'IRRIGATION

E. Cadier, P.L. Dubreuil et F. Molle

Résumé

L'emploi d'un modèle hydrologique et de simulation d'aménagements permet d'analyser en détail l'influence de la taille et du nombre d'aménagements inclus dans un bassin plus important sur les régimes hydrologiques et la production agricole régionale.

1. Introduction

On observe actuellement dans la plupart des régions sèches du globe un accroissement rapide du nombre d'aménagements hydrauliques. Cet accroissement est généralement provoqué par une pression démographique, sociale et économique ainsi que par une plus grande accessibilité aux techniques d'utilisation de l'eau. Parmi celles-ci, notons celle de l'irrigation, grosse consommatrice d'eau.

Dans ce contexte d'accélération de la demande, les conflits d'utilisation des ressources en eau, qui sont par définition limitées dans les régions semi- arides, sont appelés à se multiplier.

Une fois déterminées, pour une région donnée, les ressources en eau globalement exploitables ou encore la surface totale irrigable, il reste à décider de la manière dont seront répartis les aménagements: est-il préférable d'installer un petit nombre de grands aménagements, un grand nombre de petits et micro- aménagements, ou encore une solution intermédiaire?

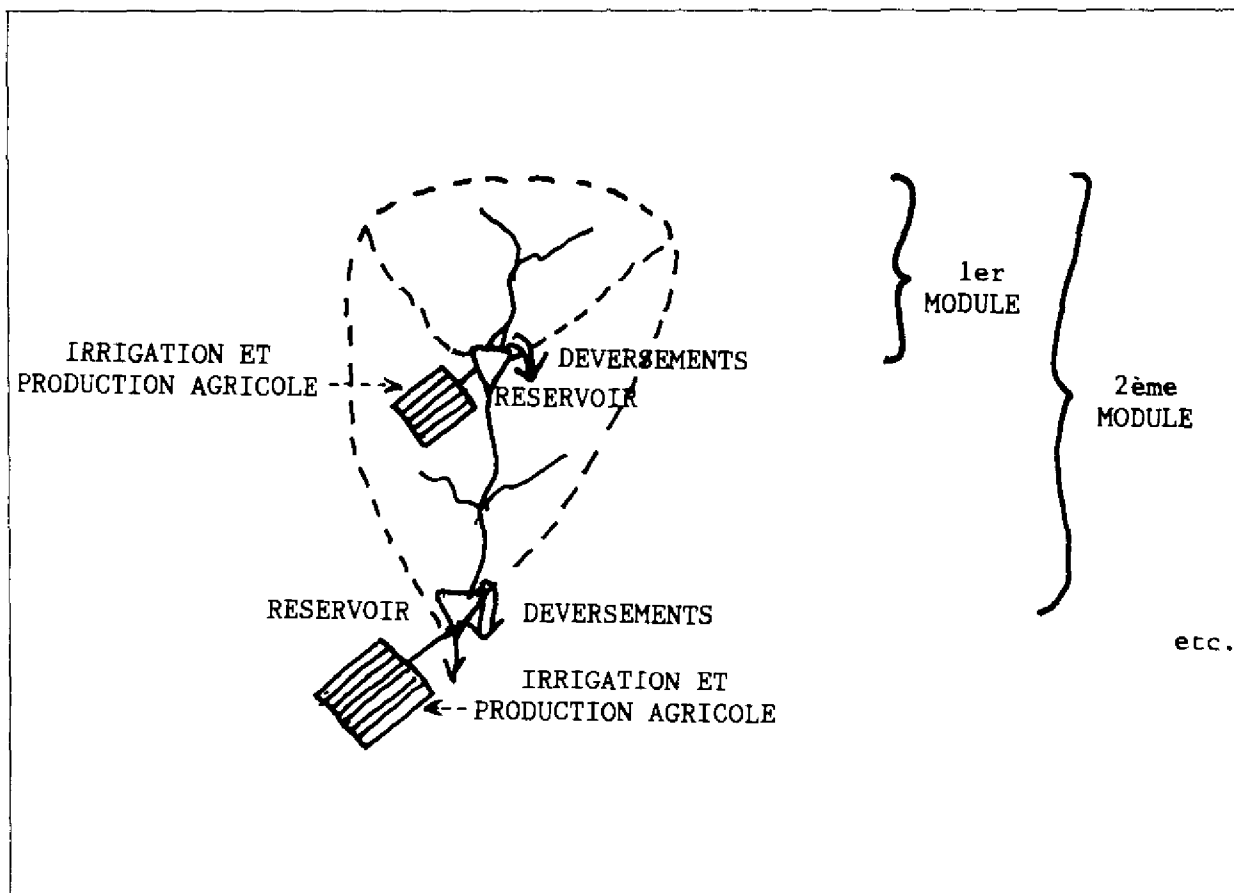
Si l'on ne considère que les aménagements hydrauliques qui utilisent une retenue pour stocker l'eau, on sait déjà que les petits et micro-aménagements autorisent une plus grande souplesse, car ils favorisent les exploitations individuelles ou de petites communautés en limitant ainsi les déplacements de population. Ils permettent aussi d'utiliser des sites et des périmètres de petite taille inexploitable par des aménagements plus grands. Par contre, les grands aménagements permettent de mieux résister à de longues périodes sèches, la régularisation étant facilitée par une plus grande profondeur des retenues qui diminue l'influence relative de l'évaporation. Il est, par ailleurs, plus facile d'exercer le contrôle agronomique d'un grand périmètre et d'organiser la commercialisation de sa production.

Le modèle de simulation d'un système de réservoirs et de périmètres d'irrigation emboîtés et de taille variable que nous présentons ci-après fournit des éléments d'appréciation qui facilitent la rationalisation des choix des tailles optimales et du nombre des aménagements. Ce modèle permet de comparer la gestion des ressources en eau et la production agricole selon plusieurs hypothèses d'agencements des aménagements.

2. Description sommaire du modèle utilisé

Le modèle³⁸ utilisé est dérivé du modèle décrit par F. Molle, 1985 et par E. Cadier et P. Dubreuil, 1986.

Il comporte plusieurs modules emboîtés. Chacun de ces modules simule le fonctionnement d'un périmètre d'irrigation avec son réservoir et son bassin hydrographique d'alimentation qui peut lui-même englober un autre module.



Chaque module associe donc un modèle hydrologique et un modèle simulant le fonctionnement d'une retenue alimentant un périmètre d'irrigation au pas de temps journalier. Cette simulation permet l'analyse statistique du comportement de tous ses

³⁸ Conçu par ORSTOM et SUDENE, Surintendance de développement du Nordeste

composants: pluie, débits entrant et sortant de la retenue, volumes stockés et évaporés dans celle-ci, volumes utilisés par l'irrigation, surface moyenne cultivée, rendement et production des cultures.

La retenue est définie par sa profondeur maximale H_x et son volume V tel que $V = K.H_x^\alpha$ avec K coefficient d'ouverture et α coefficient de forme.

La simulation de l'irrigation calcule chaque jour les consommations et la croissance des cultures en fonction de l'eau disponible dans le sol. Elle détermine les doses d'irrigation et les surfaces à planter, à récolter ou à abandonner en fonction des besoins en eau des cultures déjà plantées, des réserves en eau dans le réservoir et dans le sol du périmètre ainsi que des prévisions sur les pluies et écoulements à venir selon la saison.

3. Mise en oeuvre de cette modélisation

La mise en oeuvre de cette modélisation s'est effectuée sur un cas concret que l'on peut caractériser comme suit:

3.1 Entrées du modèle

Nous avons choisi un pluviomètre et un bassin hydrographique d'alimentation situés dans le Nordeste brésilien comme "entrée" du modèle.

La pluviométrie annuelle moyenne de ce pluviomètre est de 685 mm calculée sur la période 1911-1983.

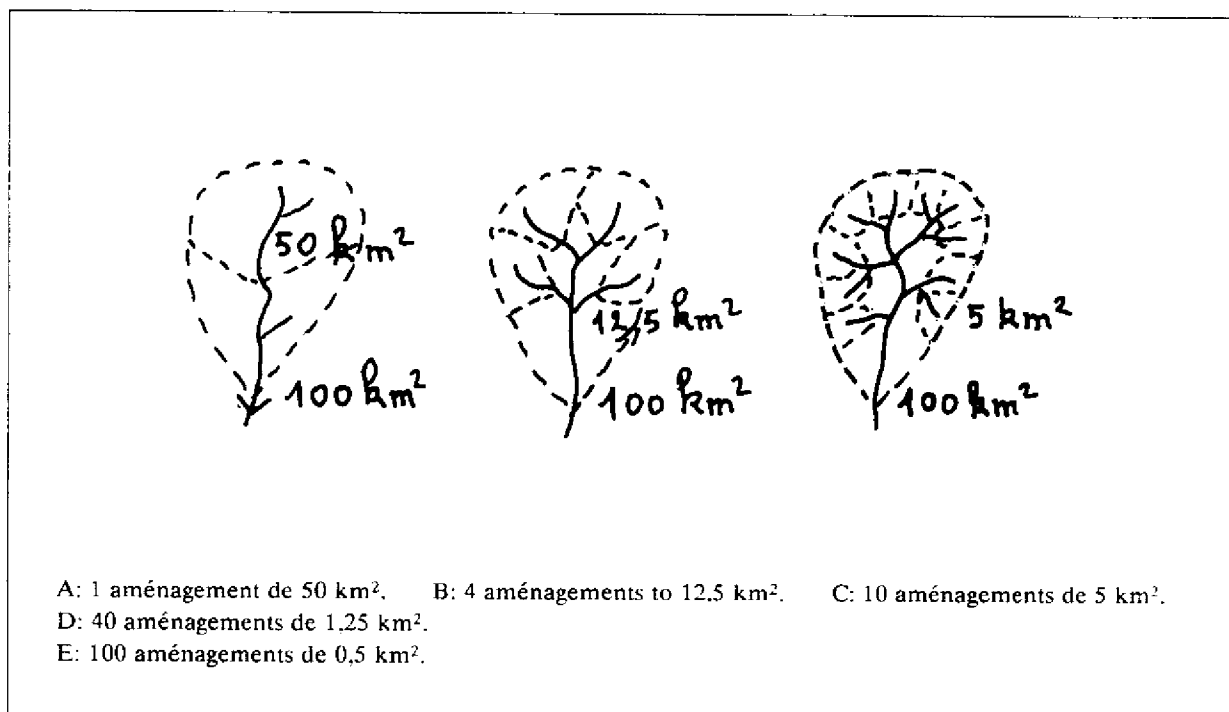
La variabilité interannuelle de l'écoulement du bassin choisi est représentée dans le tableau suivant:

Lame d'eau annuelle	(mm)
Maximale	410
Décennale humide	232
Médiane	56
Décennale sèche	0
Moyenne	89

3.2 Caractéristiques des simulations réalisées

Pour mettre en évidence l'influence de la taille et du nombre d'aménagements inclus dans un bassin plus grand, nous avons réalisé cinq simulations représentant le même bassin de 100 km² aménagé de plusieurs façons différentes.

a) On étudie un aménagement utilisant un "grand bassin" d'une surface totale de 100 km² dont 50 pourcent de la surface est contrôlé par un ou plusieurs aménagements suivant le schéma suivant:



b) Chaque aménagement est équipé d'un réservoir et d'un périmètre de taille proportionnelle à l'écoulement moyen dont les caractéristiques varient de la façon suivante en fonction de la taille du bassin (les écoulements générés sont proportionnels aux tailles des bassins).

SB (km ²)	0,5	1,25	5	12,5	50	100	SP
SP (ha)	1,07	2,68	10,7	26,8	107	149	VX
VX (10 ³ m ³)	44,3	111	443	1 108	4 431	6 164	K
K	735	9 626	1 190	2 446	3 930	8 099	
α	2,7	2,7	2,7	2,7	2,7	2,7	HX
HX (m)	4,56	5,36	6,86	8,08	10,33	10,95	

SB = Surface du bassin d'alimentation
 SP = Surface installée du périmètre irrigué
 VX = Volume maximum de la retenue
 HX = Profondeur maximum de la retenue
 K = Coefficient d'ouverture du réservoir
 α = Coefficient de forme du réservoir
 (défini par $V = KH^\alpha$)

Notes:

b1) L'augmentation des coefficients d'ouverture (K) des retenues avec leur taille reflète le fait que les grandes retenues situées sur de grands bassins auront des formes plus ouvertes ou plus évasées que des retenues situées sur de petits bassins.

b2) Les caractéristiques du périmètre et du réservoir de la dernière colonne du tableau ci-dessus correspondent à un bassin de 100 km² dont 50 km² sont contrôlés par des aménagements plus petits.

b3) L'hypothèse de la proportionalité des écoulements aux surfaces et de celle des périmètres installés aux écoulements implique que la somme des surfaces des périmètres irrigués installés soit constante. Cette surface totale installée est de 256 ha composés de 107 ha de petits aménagements et de 149 ha de l'aménagement principal.

3.3 Caractéristiques des cultures

On a supposé que le périmètre d'irrigation était planté de tomates dont la consommation en eau est caractérisée par le tableau suivant:

Phase du cycle végétatif (jours)	0	30	50	75	100	120
Kc	0,40	0,70	1,0	0,8	0,6	
Ky	0,4	0,4	1,1	0,8	0,4	

$$Kc = \frac{\text{ETM Consommation réelle maximale}}{\text{ETP Evapotranspiration Potentielle}}$$

$$Ky = \frac{\text{Déficit de production}}{\text{Déficit hydrique}}$$

Le rendement maximum de la tomate est de 25 t ha⁻¹ pour un prix de 1,2 Cz par kilogramme.

4. Analyse des résultats de simulations

Nous avons sélectionné quelques résultats de simulations qui mettent en évidence les différences de comportement des différents systèmes.

4.1 Bilan hydrique des retenues

Examinons les variations des moyennes des principaux termes du bilan hydrique des retenues résumées par la figure 1 et dans le tableau suivant:

Nombre d'aménagements	100	1	Accroissement	
Surface de chaque aménagement (km ²)	0,5	50	Mm ³	%
<hr/>				
Volume utilisé pour l'irrigation (Mm ³)				
Aménagement principal	2,38	2,39	0,01	0,5
Petits aménagements	1,41	1,93	0,52	37
Total	3,79	4,33	0,54	14
<hr/>				
Volume évaporé dans les retenues (Mm ³)				
Aménagement principal	1,27	1,28	+ 0,01	+ 1
Petits aménagements	2,01	1,09	-0,92	-46
Total	3,29	2,28	-0,91	28
<hr/>				
Précipitations directes sur les retenues (Mm ³)				
	1,08	0,73	-0,35	-32
<hr/>				
Volume déversé en aval de l'aménagement principal (mm ³)				
	2,91	2,92	0,01	0,3

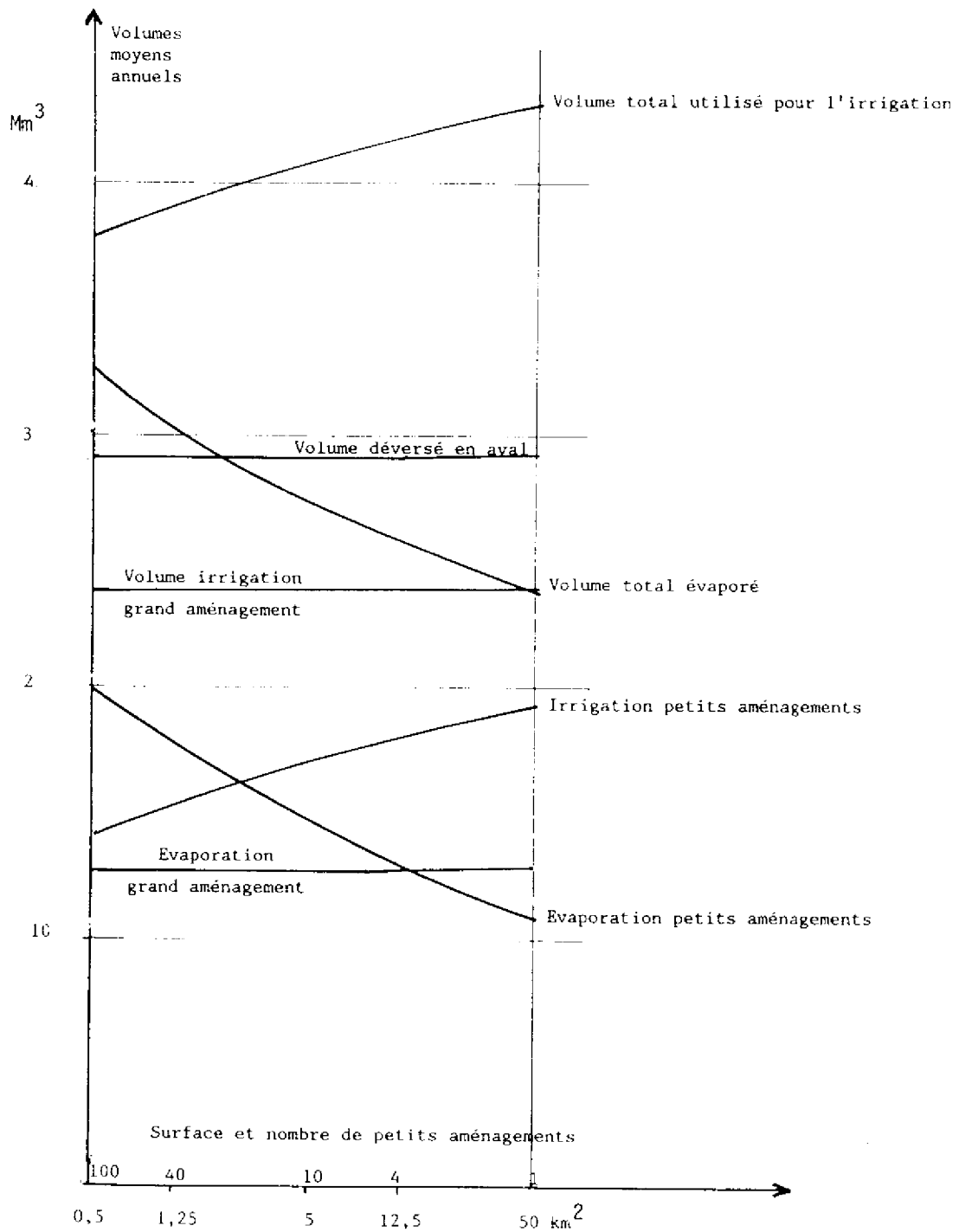
Comme on pouvait le prévoir, la multiplication du nombre des aménagements diminue la proportion des ressources en eau réellement utilisées, on passe par exemple d'une utilisation de 4,33 Mm³ à 3,79 Mm³ quand on passe d'un petit aménagement de 50 km² à 100 de 0,5 km².

Cette figure et ce tableau montrent de plus que cette dégradation provient presque exclusivement des variations des termes du bilan des petites retenues.

4.2 Variation de la production agricole

L'analyse du tableau suivant et des figures 2 et 3 montre que la variation de production agricole moyenne est du même ordre de grandeur que celle de la quantité d'eau utilisée pour l'irrigation. Ainsi, lorsque l'on compare le cas de 100 aménagements de 0,5 km² à celui de l'aménagement de 50 km², un accroissement de 14 pourcent de l'eau utilisée provoque un accroissement de 13 pourcent de la production tandis que la surface cultivée

Fig. 1 ELEMENTS DU BILAN HYDRIQUE DES RETENUES



: Nombre d'aménagements	: 100	: 1	: Accroissement	:
: Surface de chaque aménagement (km ²)	: 0,5	: 50	: 10 ⁶ Cz	: %
: (Petits aménagements	: 3,93	: 5,22	: 1,29	: 32
: Moyenne (Aménagement principal	: 6,49	: 6,55	: 0,06	: 1
: (Total	: 10,42	: 11,77	: 1,35	: 13
: Décennale (principal	: 0	: 0,82	: 0,82	: -
: sèche (aménagement principal	: 0,38	: 0,38	: 0	: 0
: (Total	: 0,38	: 1,20	: 0,82	: 215
: Triennale (Petits aménagements	: 2,50	: 4,06	: 1,56	: 62
: sèche (Total	: 6,97	: 8,53	: 1,56	: 22
: Médiane totale	: 12,82	: 14,60	: 1,78	: 13
: Triennale humide totale	: 15,06	: 15,36	: 0,30	: 2
: Surface cultivée moyenne	:	:	:	:
: Petits aménagements	: 75,2 ha	: 90 ha	: 15,6 ha	: 20
: Aménagement principal	: 123,6	: 124,0	: 0,4	: 0,3
: TOTAL	: 198,8	: 214,8	: 160	: 8

moyenne ne croît que de 8 pourcent. (Rappelons que la surface totale installée est constante et égale à 256 ha).

Ici encore, nous constatons que la plus grande partie des variations de production proviennent des petits périmètres.

L'analyse des productions correspondantes à des périodes de retour déterminées (décennale, triennale, médiane, etc.), montre que les petits aménagements résistent comparativement beaucoup plus mal aux années de sécheresse.

Ainsi, la production décennale est nulle sur un aménagement de 0,5 km²; pour une année sèche triennale, on constate un accroissement de 62 pourcent de la production entre les 100 aménagements de 0,5 km² et celui de 50 km² au cours d'une année sèche triennale alors que la production totale ne varie que de 22 pourcent.

Par contre, pour une année triennale humide, il n'y a pratiquement plus de variation de production quand change le nombre d'aménagements.

4.3 Explications complémentaires

Pour ne pas alourdir notre exposé, nous avons rassemblé ci-après un certain nombre de commentaires et d'explications complémentaires:

a) Invariance du comportement du grand aménagement aval

On constate que les bilans en eau et les productions agricoles du "grand" aménagement aval ne dépendent pratiquement pas du nombre des aménagements en amont. Ceci peut s'expliquer qualitativement par deux raisons:

a1) On constate une très faible variation des déversements des retenues amont en fonction de leur taille. Ces déversements proviennent de crues généralement groupées sur une faible période. Les premières crues rencontrent presque toujours une retenue vidée par l'évaporation et les prélèvements pour irrigation; les crues suivantes surviennent dans une période trop courte pour que l'effet des différentes tailles de retenues ait pu se faire sentir sur les volumes évaporés.

a2) Pendant les *années déficitaires*, aucune retenue, grande ou petite, ne déversera. Il n'y aura donc pas d'influence des aménagements amont ces années-là.

Pendant les *années excédentaires*, les déversements amont seront souvent inutilisés, car les bassins intermédiaires produiront généralement assez d'eau.

b) Dimensionnement des périmètres d'irrigation

L'hypothèse adoptée de proportionnalité entre les écoulements moyens et les surfaces installées biaise un peu les résultats pour les raisons suivantes:

b1) pour les "petits" aménagements, il faudrait considérer le volume réellement disponible, c'est-à-dire, le volume écoulé moins l'évaporation dans la retenue. L'hypothèse que nous avons adoptée surdimensionne légèrement les surfaces des petits aménagements et donc leur production.

b2) Pour les raisons exposées en a2), il serait préférable de ne pas tenir compte des écoulements déversés par les aménagements amont pour le dimensionnement du "grand" périmètre aval qui est surdimensionné de 20 à 30 pourcent par rapport aux autres.

c) La fréquence de 0,90 (décennale sèche) est proche de la fréquence de production nulle.

Fig. 2 VARIATION DE LA PRODUCTION MOYENNE ANNUELLE

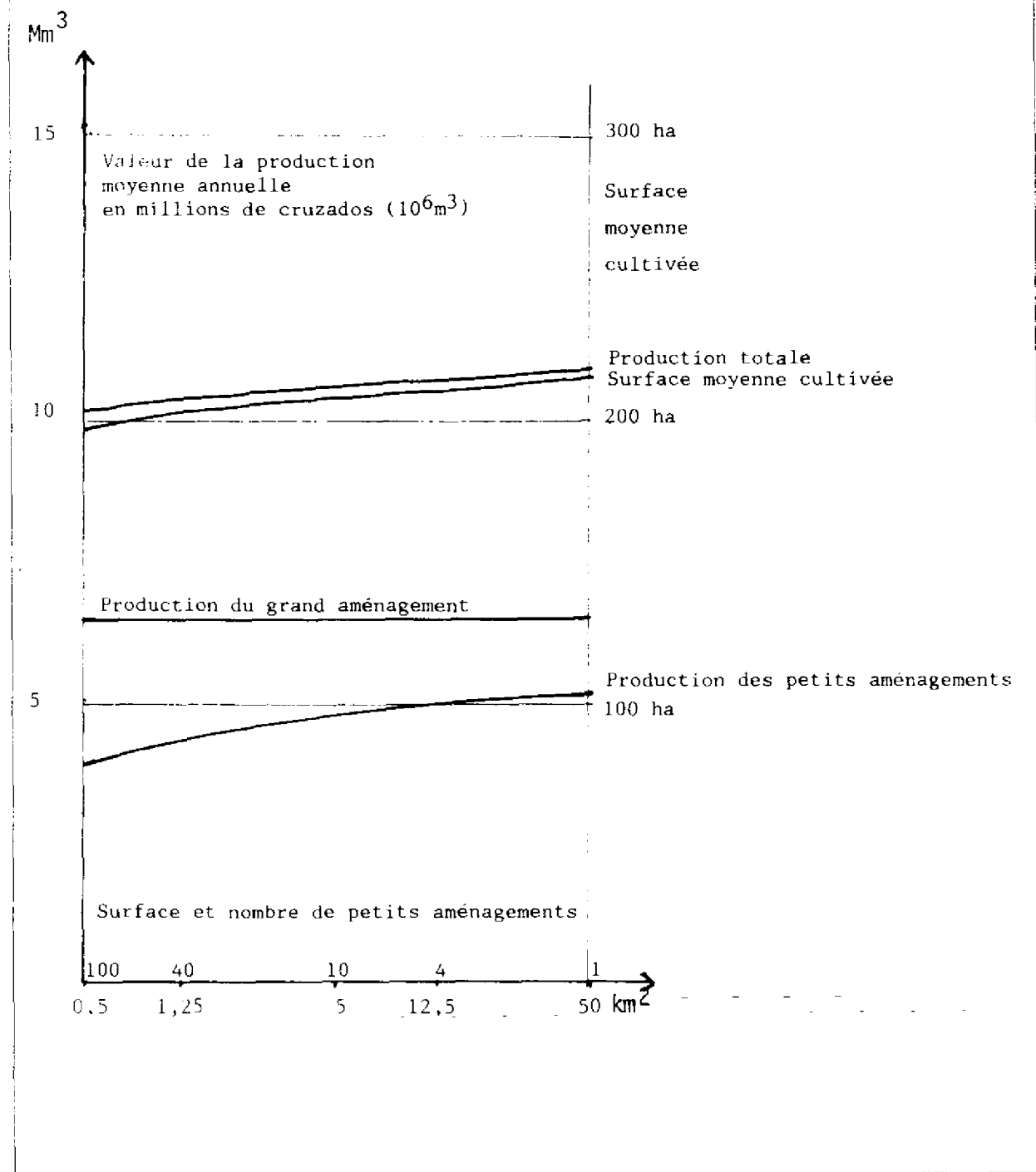
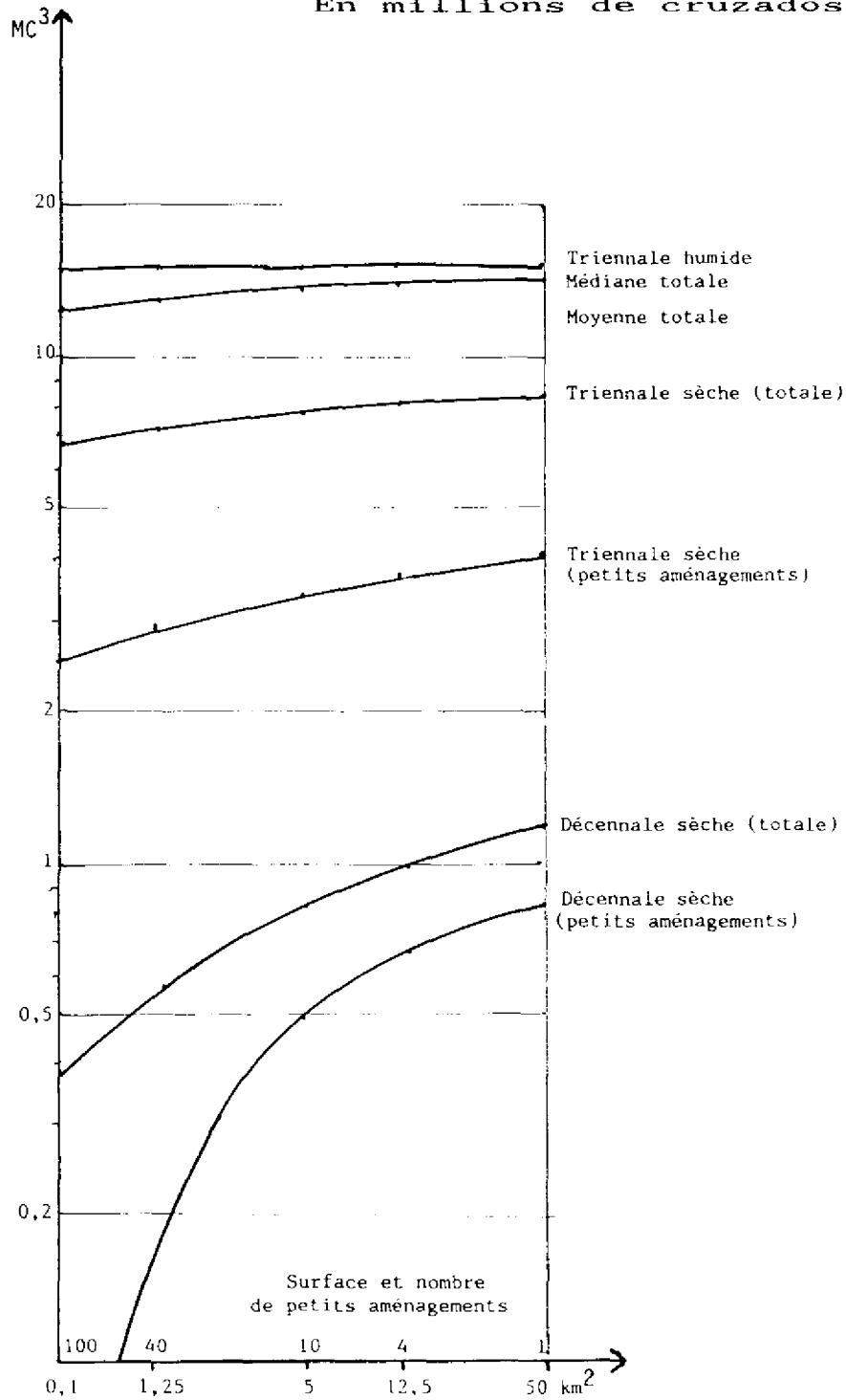


Fig. 3 PRODUCTION ANNUELLE
DE DIVERSES FREQUENCES
En millions de cruzados



Surface du bassin (km ²)	0,5	1,25	5	12,5	50
Fréquence de production nulle	0,80	0,91	0,92	0,95	0,96

Les productions de ces années sèches correspondront souvent à un contexte de réduction de doses et de surfaces irriguées dont le succès ou l'échec dépendra de peu de choses. Ainsi, il est parfaitement explicable qu'un surdimensionnement du grand périmètre ait conduit à épuiser trop vite les réserves. Ce qui explique une récolte paradoxalement plus faible (0,38 MCz au lieu de 0,82 MCz pour la production décennale sèche du tableau du paragraphe 4.2).

d) Enfin, signalons que, au cours des *années excédentaires*, le facteur limitant de la production ne sera plus la quantité d'eau disponible mais la surface installée du périmètre ou encore le volume du réservoir. Ceci explique un certain "tassement" des productions quand la pluviométrie s'accroît.

5. Conclusions

Ce modèle de simulation nous a permis d'effectuer une analyse fine du comportement hydrique, de la production agricole et des interactions existant dans un ensemble d'aménagements hydrauliques emboîtés.

Nous avons supposé que, à l'amont d'un aménagement hydraulique destiné à l'irrigation et emmagasinant l'eau dans une retenue, il existait un nombre variable de retenues plus petites. Une hypothèse supplémentaire nous a conduits à faire varier le nombre et la taille de ces petits aménagements de telle façon que la surface totale contrôlée soit constante ainsi que la somme des surfaces irriguées par les petites retenues.

Dans ces conditions, nous avons montré que:

a) Les régimes hydrologiques à l'aval de la grande retenue et sa production ne sont pratiquement pas affectés par la taille des aménagements existant en amont.

b) La production agricole moyenne totale de l'ensemble n'est que peu affectée par la taille des "petits" aménagements. Ainsi, on constate une diminution de 13 pourcent de la production totale quand le nombre de "petits" aménagements en amont passe l'aménagement contrôlant un bassin d'alimentation de 50 km² à 100 aménagements contrôlant chacun 0,5 km².

c) Par contre, au cours des années sèches, la production des petits aménagements diminue beaucoup plus rapidement que celle des aménagements plus importants.

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THEME IV

**METHODOLOGIES FOR THE ASSESSMENT OF IMPACTS - INTERNATIONAL
ENVIRONMENT ASSESSMENT IN LARGE INTERNATIONAL RIVER BASINS**

PAPER 34

PLANNING THE OPERATION OF WATER-MANAGEMENT SYSTEMS: A COMPLEX APPROACH

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Summary

Modern water-management systems are representative of complementary use of water resources and display intricate links both at the level of individual water works and water systems. These links may be hydraulic or concern power production, may manifest themselves hydrologically, or be associated with water consumption. Two major problems arise in this connection: first, to revise the methodology of regime analysis, and to reconsider or generalize concepts formed at the time when solitary reservoirs were representative of the water management pattern; second, at the stage of transition to the construction of reservoir in series, to tackle the problems associated with integrated water-and-power systems as well as some insufficiently developed concepts in the theory of water-system operation.

Methods of water quality control together with hydraulic and conservation short- and long-term goals in the planning of water management systems operation are given below. The author suggests a multilateral approach to the above problems, based on the information interconnection between them. A water pollution control subsystem is briefly described which is incorporated into an automated system of observation and control of the environmental conditions.

Modern water management systems are representative of complementary use of water resources, which reveal their multipurpose character in the intricate links existing both among water management systems and the individual water works. These links manifest themselves in the following forms:

1. Hydraulic links

Hydraulic links occur when several headworks are situated on the same river, or on a river and its tributaries thus forming a cascade (e.g. the Volga-Kama, Angara-Yenise, the Dnieper headworks cascades, etc.). The operational regimes of headworks are interconnected and therefore, from the viewpoint of flow regulation, a cascade should be considered as an entity and not as independent water works.

Artificial links established for the sake of transport or for whatever other purpose represent another variant of inter-basin hydraulic liaisons (e.g. the Volga-Don Canal).

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2. Links introduced due to water consumption.

Water needs of certain water-consuming facility, such as an irrigation scheme, can be met from different reservoirs (for instance, the Tsimljanskoye reservoir on the Don and the Volgogradskoye on the Volga). Then, given that the total water consumption remains unchanged, the delivery of water to the consumers from one reservoir will depend on that from the others even if no hydraulic links exist between them.

Hydrological links

Hydrological links arise from the fact that the natural inflow to reservoirs, even if these are constructed on different rivers, are more or less stochastically interdependent.

Consequently, when modelling the natural inflow to reservoir cascades a correlation of inflows to individual reservoirs should be taken into account (as for example in the case of the Volga-Kama cascade).

4. Links imposed by power generation.

Links exist when the power generated by hydropower stations supplied by reservoirs is fed into an interconnected system. In this case the reservoir discharge for power generation depends on that of other reservoirs as well as on the storage of the reservoirs since these determine the hydraulic head at the power station.

Interconnected systems have proved to be the most economic method of managing the power-generation industry. At present the USSR disposes of the Unified Power Supply System comprising the energy grids of the European USSR and of central Siberia. The unification of power systems of the CMEA countries is progressing and studies are in hand to connect the CMEA and the West European grids.

The links established due to power generation bring about the creation of a unified power-and-water system in which thermal-power stations depend not only on the regime of hydropower units but also on the water management of the system.

These links lead to the consideration of two major problems.

First, the transition from the era of isolated reservoirs providing for no cascades, to that of water-management systems (comprising at least two reservoirs) is a development which calls for a different operational regime analysis and, moreover, for the reconsideration or generalization of a host of concepts valid when solitary reservoir construction had been the natural pattern.

Water-supply deficiency (shortage or complete lack of water supply to water users and consumers) is one of the possible occurrences. Depletion of live reservoir storage means water shortage for both users and consumers, and when a water system (comprising more than a single reservoir) is involved the result may be ambivalent in terms of water deficit.

The schedule used for the control of single reservoir operation as a compensation for lack of hydrological forecasts is unsuitable for reservoir systems. The plot of this schedule for a system having reservoirs would require an $x+1$ -dimensional space (one coordinate is for time, the other coordinate is for storage of x reservoirs). It is apparent that from geometrical standpoint the operational schedule is valid only for $x=2$.

For a system of reservoirs an operation schedule algorithm is required rather than the schedule itself. The problem of algorithmic control is discussed in many papers, some of which are listed in Cvetkov, 1984) but the problem is not dealt with exhaustively, since proper attention is not given to qualitative analysis of processes and calculation of results, or to the application of hydrological forecasts which are the key to operational control.

A number of examples point to the fact that the present stage of water-management development requires the generalization of some concepts and the need to create a unified theory of water systems.

The transition to reservoir systems raises the problem of the multidimensionality of multipurpose water systems, since a theory suitable in essence for a system of any complexity does not guarantee the solution of the problem in cases difficult for computer implementation.

In order to simplify a water-management system, the impact of a part of the system's components on other components is often considered as a minor disturbance. This procedure consists of the three following parts:

- 1) study of major components operation without disturbing components;
- 2) study of disturbing components operation proceeding from the assumption that the major components are operating without disturbances (as is in the first part);
- 3) identification of corrections in major components operation caused by disturbing components.

In some instances it was possible to simplify the problem by involving another idealization (Kartvelishvili et al. 1976) by using a transition from a system consisting of some components to a system with a certain continuity.

So far as concerns water-resources management, the basic task is to develop an optimizational regulation theory providing for flow forecasts, as the theory of flow regulation dealing with a pre-assigned yield can be considered to have been accomplished.

It should be pointed out that the current practice of design and construction of large canals is based on the solution of water friction. The design formulae available are experimental and apply to a certain range of channel dimensions (mainly for channels with hydraulic radii not exceeding 5 m). If these formulae are extrapolated beyond the limits for which they were developed, results may prove to be wrong.

The creation of the theory of water systems enabling multilateral water management tasks to be studied as an entity, leading to more reliable solutions and thus to the more efficient use of water resources, suggests that the following problems will have to be resolved:

- (a) Mathematical description of water systems and formulation of basic concepts and definitions associated with these systems.
- (b) Development of methods for overcoming the multi-dimensionality of water-and- power systems.

- (c) Development of an optimization theory for flow regulation by means of a system of reservoirs.
- (d) Improvement of a mathematical model of natural water inflows into a system of reservoirs as a probability process and accounting of hydrological forecasts in this model.
- (e) Identification of parameters of the model of natural inflow into reservoirs in the case of insufficient observation data.
- (f) Assessment of water friction in large canals.

The regulation of water resources, including their protection against depletion and contamination, presents a difficult and sophisticated problem. The regulation of water quality may be achieved by one of the following methods:

- changes in water level and flow velocity conditions, including those occurring for short periods of time (within the limits of hydraulic possibilities and taking into account the water users' needs). This permits an influence to be exerted on the content of organic and biogenic matter in water;
- construction of regulation storage (reservoirs, stilling pools, etc.) to control dilution and the self-clarifying capacity of a water body and to increase allowable changes in its water levels and flow velocities.
- construction of selective intakes (with small amounts of water withdrawn for the needs of water users) in the case of thermal stratification and, consequently, the uneven subsurface distribution of a number of water quality indices. These intakes enable the supply of water of different quality from different layers of the water body to meet the needs of various categories of water users (for example, water from the bottom layers poor in oxygen and rich in biogenic matters can be conveyed into a reclamation network while water from surface layers rich in oxygen can be used for the needs of domestic and potable water supply, etc.);
- hydraulic design of canal linings which have an influence on biogenic and organic water quality indices;
- technical measures (planting of hydromacrophytes on banks, creation of a biological plateau, artificial aeration of bottom layers in water bodies, application of coagulants and serbents, harvesting of higher aquatic vegetation, gathering and subsequent removal or utilization of extinct phytoplankton, withdrawal of contaminated bed loads, etc.). These measures are aimed at activating the aquatic ecosystems, constraining the advent of matters and their further use in biochemical cycles and transforming the water's chemical composition;
- water-protection measures on catchment areas (constrained disposal of waste water, its better pre- and final purification, use of closed and quasi-closed systems of industrial water supply, introduction of wasteless and low-waste technologies, etc.), thus reducing the amount of matter entering water bodies.

The first three measures are connected, directly or indirectly, with the main water management and hydraulic problems of planning water-management systems operation.

This kind of planning usually comprises advanced, long-term and short-term planning. The advanced planning (for a period from 5 to 15 or 20 years) is associated with the planning of the system development and is not discussed here.

Routing of flood or release waves may be neglected in long-term planning, only their lag time being allowed for. During short-term planning accounting for the process of flood or release wave routing is essential. In the case of the Volga-Kama system of reservoirs long-term planning implies planning for a year, a quarter or a month, while short-term planning involves ten days, a week, a day or a few hours. In order to take into account the process of wave routing in short-term planning, the unsteady flow is estimated in the reaches of a system.

To assess the future flow parameters on the basis of existing hydrological data, probabilistic methods are applied, and use is made of hydrological forecasts to enhance the accuracy of assessment. Under water-deficit conditions, i.e. when it is impossible to supply water to all users, problems pertaining to water distribution have to be solved as well. Then, based on the expected water releases to lower pools of the headworks, flow parameters are specified under steady and unsteady flow conditions for reaches of the system.

It is recommended that the following interconnected problems of long- and short-term planning of water-management system operating regimes be solved:

1. Modelling of natural inflow into the reservoir system.

For example, a mathematical model of natural inflow into reservoirs of the Volga-Kama cascade takes account of the stochastic relationship between inflows into various reservoirs and the inflow into the first-step cascade reservoirs, as well as lateral inflows. As a result, probabilistic parameters of natural water inflows into the reservoirs of the system are calculated.

2. Calculation of the long- and short-term flow regulation.

Proceeding from the results obtained, regulated monthly, ten-day and daily average discharges at all the headworks of the system are estimated.

3. Long- and short-term planning of water distribution among users.

The major water users and consumers of the Volga-Kama basin are hydropower stations, water supply systems, irrigation, river transport, fisheries.

The problem is tackled under water shortage conditions so as to meet the requirements of water users. Curves are plotted of constrained water consumption for various periods of time.

4. Estimation of steady flow in reaches of the system.

5. Estimation of unsteady flow in reaches of the system.

When solving these two problems, use is made of the information obtained while calculating the flow regulation. For instance, in calculating the steady and unsteady flows in the lower pool of the Votkinsk hydropower station on the Kama River, use is made of discharge regulation values estimated at the site of the Votkinsk headworks. The solution

has resulted in data being obtained for levels, discharges and mean flow velocities at control sections of the lower pool.

6. Forecasting of water quality variations in reservoirs and water bodies of the system (by means of water-quality models).

A water-quality model is a set of expressions which determine physical, biological and chemical processes occurring in the aquatic medium (Loucks et al. 1981). The processes are based on a mass balance estimated with regard to the three phenomena: an advent of components into the aquatic medium from the outside, components transported in the medium proper and process interactions that either increase or decrease the concentration or mass of the components. Natural processes, as well as domestic, industrial and agricultural waste discharges are considered as sources of pollution. The waste discharges are assigned as point or distributed flows.

Output information obtained after the solution of each of the above problems becomes (partially or completely) input information to be used when tackling the other problems.

This complex approach to the problem makes it possible to plan the operating regimes of water-management systems with due regard to water- resources conservation.

An automated system of observation and control of the environment has been elaborated in the USSR for the monitoring of relevant quality indices variation in time and space. The system operates within the framework of the State Environment Pollution Control Service and comprises air and water pollution control subsystems.

The water pollution control subsystem of the Moskva River, for example, is based on hierarchical control. The subsystem's initial element includes automatic stations for surface water control. The stations are designed for automatic water sampling, determination of its physical properties and chemical composition, as well as the transformation of data obtained to convey them through communication channels to the dispatching and computing centres for processing. The automatic station is designed to measure water levels and a number of water quality parameters, such as the acidity or alkalinity, electrical conductivity, temperature, turbidity, dissolved oxygen content, etc. The number of parameters under control can easily be increased. Water sampling can be either continuous or intermittent according to the dispatcher's choice.

The subsystem incorporates a laboratory for non-automated acquisition of information that cannot be obtained from stations (such as data on complex pollution required for specific analyses). The subsystem ensures water pollution forecasts which allow sufficient time for measures to be taken to avoid unacceptable pollution levels.

The implementation of a water pollution control subsystem entails a considerable economic impact due to the reduction of the cost of collecting the information on water quality and makes for more reliable information.

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PAPER 35

A CRITICAL ANALYSIS OF THE ENVIRONMENTAL IMPACT ASSESSMENT EXPERIENCE IN DEVELOPING COUNTRIES: THE CASE OF TUCURUI DAM IN BRAZILIAN AMAZONIA

Elizabeth Monosowski

Abstract

Environmental Impact Assessment (EIA) can play an important role, as a planning tool for development, contributing to the discussion of more appropriate alternatives, based on a country's socio-ecological potentialities, and better adapted to the new situations to be faced in the actual crisis period.

The actual experience with EIA in developing countries shows that in many cases, it has been incorporated as an "add-on" to the current procedures, and presented as a substitute to the adoption of broader environment/development policies, planning and management. This has led to unrealistic expectations on the role and possibilities of use of these tools for environmental management, and consequently to a certain discredit of their effectiveness.

The point of departure of this paper is the practical experience with the EIA of the Tucuruí Dam in Brazilian Amazonia. This case study is being analysed in order to identify and discuss some of the key issues involved in the transfer of these methodologies and procedures to the context of a developing country. Among aspects to be examined, the following should be mentioned:

- a) the conceptual framework and the choice of a methodological approach affect the final results.
- b) are mitigating measures adequate and do they reflect the social values, needs and expectations?
- c) EIA and decision-making: the role of the different social actors in the decision cycle; institutional constraints and opportunities for the implementation of mitigating measures.

In conclusion, some principles are recommended with respect to strategic approaches for the promotion and support of EIA in developing countries.

1. Introduction

Environmental Impact Assessment (EIA) can play an important role as a planning tool for development, contributing to the discussion of more appropriate alternatives, based on a country's socio-ecological potentialities, and better adapted to the new situations to be faced during the actual crisis period.

The actual experience with EIA in developing countries shows that in many cases, however, it has been incorporated as an "add-on" to the current procedures, and presented as a substitute to the adoption of broader environment/development policies, planning and management. This has led to unrealistic expectations concerning the role and possibilities of using these tools for environmental management, and consequently to a certain discredit of their effectiveness.

An increasing interest is being shown in some of the early experiences in the practice of EIA on large-scale water projects in developing countries. Those projects have been usually taken as a development factor, providing the infrastructure for introducing new forms and scales of production in Third World countries. However, they have also been a source of significant environmental and social change. Their social and environmental costs have very often outweighed their expected benefits, which explains the interest shown in adopting EIA for evaluating this kind of project.

This paper discusses the practical experience gained on the EIA of the Tucuruí Dam, in Brazilian Amazonia. This was one of the first EIAs ever carried out in this region, and its results have certainly influenced some of the later environmental policies adopted by the Brazilian electrical sector. This case will serve to identify and discuss some of the key issues involved in the transfer of EIA methodologies and procedures to the context of a developing country. A critical review of the problems faced and possible ways of solving them may contribute to making this tool more suited to local conditions.

2. Tucuruí Dam: a case study

The Tucuruí scheme, built by the national electrical utility for the Northern region - ELETRONORTE - on the Tocantins River, is the biggest hydropower plant in Amazonia and the second largest in Brazil. The Tucuruí Dam, 300 km south of Belem, the main city of Eastern Amazonia, backs up water for 200 km along the Tocantins River. Flooding the surrounding forest area, it created a reservoir within an area of 2 480 km². The accumulation of 43 m³ of water will generate 4 000 MW in the first stage, and the final installed capacity will be 8 000 MW, making Tucuruí the world's third largest hydropower scheme in terms of installed capacity.

This energy is a basic input for the Grande Carajas development programme, a group of large projects, extending over an area of about 400 000 km², in the Eastern Amazon, to exploit the local natural resources. Tucuruí provides low-cost energy for the various components of the programme, such as bauxite-alumina smelters at Vila do Conde and Sao Luis, opencast mining at Serrados Carajas and an 876 km-long iron ore railway. Belem and part of Brazil's Northeast region will also be supplied with power from Tucuruí.

The Tucuruí scheme is very important for the economic development of the whole Amazon area, but the environmental impacts, if neglected, could have an extremely negative effect, even endangering the very existence of the project. There has been much concern among the scientific community, and the public, because Tucuruí reservoir is at present the largest man-made lake ever built in a tropical forest area, and one of the biggest in Brazil. Moreover, its environmental impacts are difficult to assess: the Amazonian ecosystems are very complex, diverse and almost unknown; in addition, the advance of the economic frontier, stimulated by major projects, is rapidly causing profound environmental changes in the whole region, making it difficult to isolate the effects of Tucuruí.

2.1. Environmental assessment studies at Tucuruí

In 1977, one year after the beginning of the construction of the Tucuruí Dam, ELETRONORTE asked for a preliminary EIA. Its scope was to evaluate the environmental and non-engineering aspects of the project, and to identify those which could potentially compromise its technical and economic viability. As the construction had already begun, no alternatives to the project, or its design, siting or implementation could be envisaged.

The preliminary study was carried out by an international expert, Robert Goodland, who adopted an *ad hoc* approach, without applying formal EIA methods. He based his report on a brief inspection of the project, on interviews with scientists, technicians and government officials, and on existing bibliographic material (Goodland, 1978). The main impacts identified were related to the flooding of the forest, the increase of endemic diseases, the effects on flora, on terrestrial and aquatic fauna, the spread of waterweeds, and the resettlement of the population, including indigenous groups.

Based on this report, ELETRONORTE asked for several studies on specific environmental elements. These were carried out by technicians and scientists from academic institutions, namely INPA (National Research Institute of the Amazon), Emilio Goeldi Museum of Para, National Centre of Primates, Evandro Chagas Institute, Federal University of Para, and Butantan Institute. The studies were divided into nine sub projects, including: quantification and degradation of the vegetation in the flooded area, cataloging of flora, impact of reservoir on endemic diseases, water quality and climatic studies, surveys of soil, ichthyofauna and control of aquatic macrophytes.

In June 1983, a diagnostic report was elaborated on environmental impacts related to the filling of the reservoir. This included aspects related to the soils, mineral resources, seismology, water quality, flora, fauna, health and existing infrastructure.

There was also a resettlement and compensation programme, which included 3 985 legal cases, concerning 17 320 people. ELETRONORTE had to relocate 13 small communities among urban and rural areas, and to open about 540 km of access roads (ELETRONORTE, 1985). The project also encroached on three Amerindian reserves, affecting at least six indigenous groups.

2.2 Conceptual and methodological aspects

No formal EIA methodology was applied to the assessment of Tucuruí Dam. The potential effects of the dam's construction and reservoir filling were identified for each isolated element by applying current scientific methods. The relationships between these elements were not systematically established: there was no comprehensive description of local ecosystems and their dynamics. The links between social and ecological factors were not established either.

The Tucuruí environment was described as a collection of juxtaposed elements. No explicit criteria were adopted in their choice, but a strong emphasis was given to the direct impacts of the project on the natural physical systems. Less importance was accorded to the indirect impacts of the project on social and economic activities.

The project was isolated from the regional context. No consideration was given to its interaction with other large-scale development projects in the region, or to the impacts of activities and structures related to the project, such as the pioneer village, or the

transmission lines. Other topics that should have been considered include the potentialities for regional development created by the increase of available energy and by the man-made lake.

Social studies related to the resettlement of population from the area to be flooded, and to the compensation measures for the loss of their land. Resettlement of populations is one of the main direct social impacts of dams: social and family ties are broken, income and food reserves decrease. The loss of the traditional land affects social groups by impairing their economic and social organization, authority and cultural systems (Goodland, 1982). In the preliminary assessment, a greater emphasis was given to the impacts on indigenous groups, probably because of international public opinion concerned with their protection. As the pressure groups, formed within the local communities, progressively acquired political clout, more attention was paid to their claims. However, other social aspects should also have to be considered in the relationship of the different social groups with the environment, such as their needs for natural resources, the techniques employed by traditional activities, the impacts of resettlement on the carrying capacity of local ecosystems or the potential immigration stimulated by large-scale projects. For example, the possibility of employment on the Tucuruí Dam site attracted to the area about ten times more people than the number of jobs effectively created.

The studies adopted limited time and space boundaries for impact evaluation. There was a strong emphasis on the effects occurring during the early stages of the project's life (construction and impounding) and in the area occupied by the reservoir and its immediate surroundings. Less importance was given to the impacts on the river basin, both upstream and downstream of the reservoir. Less attention also was paid to long-term and very uncertain effects, such as changes in climate or seismicity. Some of these studies were made in June 1983, only a few months before the filling of the reservoir. Studies of changes of salinity in the estuary due to the closing of Tocantins River in the period immediately before the local drought, and which could affect the water supply of the city of Belém, were made only a few weeks before impounding, under the strong pressure of public opinion.

Accuracy of prediction is an important problem. In all studies the authors recognized a high degree of uncertainty as to their assertions. There were often no statements about the probability of occurrence of the effects, or as to their magnitude (intensity, time/space dimensions), reversibility, social groups affected or possibilities of mitigation and control.

In addition, some effects may not have been identified because of the lack of baseline information and scientific knowledge of the natural and social system dynamics in the Amazon.

There was also a lack of selective analysis orientated towards decision-making. This was probably due to a misunderstanding of the possible role of EIA in the decision process, both by the managers and by the scientific team in charge of the studies. There was an effort to accumulate as much scientific information as possible about all the environmental elements affected, but with little emphasis on defining management strategies. Indeed, the number of effects described adequately, in terms of allowing for management actions, is small, in spite of the large amount of scientific information provided. For example, studies identified 38 different species and sub-species of mosquitoes, but did not provide much information on how to avoid their breeding in the reservoir.

2.3 *Implementing EIA recommendations*

Mitigation measures suggested were mostly related to the undesirable environmental impacts which would mainly affect the dam's construction and immediate operation (for example, the clearance of the area to be flooded).

Compensatory measures were proposed for unavoidable impacts which cannot be mitigated (such as the loss of agricultural land and resettlement of population due to the flooding of the reservoir).

Most of the proposed recommendations properly implemented were directly controlled or executed by the proponent. These included the scheme of assistance to local populations downstream, during the filling up of the reservoir; the scientific inventory of flora and fauna (including ichthyofauna); the creation of a gene bank, with the objective of preserving species of economic and scientific interest. A fauna salvage operation was also organized with great publicity, and collected more than 280 000 animals, which were released in adjacent habitats, or sent to research institutions. However, this operation was criticized by some scientists, who considered it to have been inefficient and carried out for publicity, as only a small number of the animals in the area were likely to be rescued, and most of them might die on account of the lack of food or due to survival conditions in the new habitats.

Little attention was paid to the implementation of recommendations outside the competence of the proponent (such as land-use regulations and control) or which do not compromise directly the project's feasibility (such as the spread of water-borne diseases, or the development of new economic activities in the reservoir).

In certain cases, the institutional system was not able to implement the recommendations properly because of the lack of coordination and the struggle between different interests among the sectorial agencies involved. One of the main constraints of the institutional framework is probably the lack of an effective environmental policy, accepted by all the institutions involved. This could partially explain, for instance, the failure of the clearance plan in the area to be flooded. There was no consensus about the significance of the environmental impacts of flooding the forest, nor about the minimal area to be cleared to avoid these impacts. A limited clearance plan was proposed by ELETRONORTE, for selectively deforesting about 67 000 ha (30 percent of the reservoir area). The deforestation could also have brought additional benefits, since the forest to be flooded contained an important amount of commercially valuable high quality timber. In 1980 this task was awarded by the governmental agency in charge of the clearance plan (IBDF) to a company whose main interest was to exploit the valuable timber, but with no previous experience in logging. In early 1983, this company went bankrupt as a result of technical and administrative incompetence. The clearance area was left almost untouched and only 1 000 ha had actually been cleared over this period. Faced with insufficient time before the scheduled filling of the reservoir, ELETRONORTE cleared an area of 10 000 ha immediately behind the dam. This represented only 15 percent of the area to be cleared in the initial plans, which was considered critical for the dam operation. Recent monitoring shows that effects on water quality were less negative than expected, probably because of the large amount of water and the small retention time, which favoured oxygenation in the main stream of the Tucurui reservoir. However, protruding trees still present an obstacle for navigation, recreation and fishing, and may increase the proliferation of waterweeds in the reservoir.

Some of the recommendations were not appropriate to the region's ecological and social conditions, and had to be modified. For example, the monetary compensation initially proposed for resettled people in the area of Tucuruí Dam, ignored the structure of land tenure in the region and benefitted only a few big farmers and enterprises. Small proprietors were not able to get equivalent areas, because of the large rise in land prices in the region. In addition, the number of individuals having legal, registered and undisputed proprietorships was very small (a significant number of squatters), or lived by gathering forest products such as nuts, palm-hearts, latex, timber and so on. Resettling these people without adequate compensation contributed to an increase of social conflicts in a region where land disputes, accelerating migration and severe poverty had already established a framework of acute social tensions. The compensation measures initially proposed were conceived in the context of a market economy and therefore hardly considered the relationships that different social groups maintained with the environment, thus creating some difficulties in the negotiation process. Social struggle for adequate compensation led ELETRONORTE to establish a resettlement programme which included indemnities for existing constructions and farming; the concession of urban lots with houses, or rural lots with a construction grant for rural housing ; the transportation of all family members and their belongings, including livestock, to the resettlement areas. Nevertheless, there was strong divergence regarding the value attributed by the different social groups and the proponent to the land and natural resources, or as to the adequate compensation required.

2.4 Review of the performance of the assessment process

When analysing the performance of EIA in this case study the particular conditions in which it was carried out should be taken into account:

There were no legal requirements for EIA, nor for implementing its findings and recommendations at the time the Tucuruí studies were carried out. The decision to undertake the EIA was internal to ELETRONORTE, following a directive from the Ministry of Mining and Energy. Therefore the practical results of the assessment process were almost exclusively conditioned by the proponent's own interests and institutional capacities.

Tucuruí environmental studies presupposed a social consensus as to the need of the project, probably because they were an internal activity to ELETRONORTE. Therefore, the "do-nothing" choice was never considered. However, the arguments concerning the expected benefits or the need of the project were often contested by the public, even if this was not considered as part of the EIA procedure.

As the studies were made at a late stage of project development, the choice of alternatives and mitigation measures was limited to a few marginal aspects. None implied changes in the project's conception, design or schedule. There was no possibility of considering major technological options, or of proposing structural changes to the project.

The possible roles and scope of EIA in the project cycle should also be questioned. In our case, EIA was conducted as a purely technical-scientific exercise, whose main purpose was to minimize some undesirable environmental effects and perhaps to justify decisions already made. The role of EIA was, first, to protect the investment already made and, second, to obtain public acceptance of the project.

In spite of this narrower scope, the results of this EIA are still rather unsatisfactory. This raises the question of the extent to which the EIA met its purpose. It is probably too early to be definitive about the environmental consequences of the dam. The first

monitoring results on water quality show that the situation is less critical than expected. However, at the time of writing, there are yet no conclusive results as to the medium- and long-term effects of the dam.

As for the social aspects, the EIA did not lead to acceptance of the project by a wide range of the social groups involved. Only certain elements of the academic community and of the local press changed their initial position of suspicion. One of the possible reasons for this is that, according to a technocratic decision-making process, the Tucurui EIA was designed and conducted as an internal activity, whose results should remain confidential. Consequently, it did not provide for public participation and negotiation. Another factor is that, contrary to early expectations and EIA assumptions, the major impacts of the project were probably social. The Tucurui experience has shown that assessment conducted as a closed technical- scientific exercise failed to identify some significant alternatives and impacts, especially those of importance to minority groups. Nevertheless, external factors related to the political climate at the time could also have influenced the opposition to the project. For example, the identification of large-scale projects in Amazonia with the contested military rule was certainly an important reason for the refusal of the dam by some of the social groups concerned.

The most important positive consequence of the Tucurui experience is certainly the recognition by the institutions involved in the process, of the need for environmental assessment as a useful tool for decision-making. Within ELETRONORTE, EIA has been progressively accepted as an integral part of the project cycle, yet not without some internal resistance. At any rate, a special department was created to deal with the environmental aspects of dam projects, and a permanent multidisciplinary team was hired. At present, environmental studies are made from the early project stages for all dams to be built and some changes of project conception are to be expected. ELETRONORTE can now be considered as one of the leading institutions as regards EIA in the Brazilian electrical sector.

ELETROBRAS, the national holding company for the electrical sector, is also actively supporting the use of EIA for energy-generation projects. It recently published a manual for the environmental assessment of electrical systems, which include hydropower schemes, thermal generation plants and transmission lines, in order to provide guidelines for these studies. (ELETROBRAS, 1986).

Finally, the Brazilian government formally adopted Environmental Impact Assessments as part of its decision-making process. In effect, since 1983 a federal law calls for EIA on all large-scale development projects, whether public or private. EIA regulations and procedures were established in January 1986. Among other activities to be assessed are large-scale water projects, specially hydropower and irrigation schemes.

3. Conclusions

Doubtless, the potentialities of EIA as a planning tool for environmental management were not fully explored in the Tucurui case. Conceptual, methodological and procedural improvements are still needed in order to provide for an adequate assessment of large-scale development projects which may provoke significant impacts on both the ecological and social dynamics of a whole region.

As a conclusion, some strategic approaches may be suggested:

- a) The EIA should be introduced in the early stages of the project cycle, as an integral part of the decision-making process. It is imperative that engineering and economic feasibility studies take into account the results of the environmental assessment.
- b) Integration of large-scale projects within local and regional development strategies should be a major concern. This should include a greater emphasis on exploring the opportunities for the development of new economic activities potentially created by the project. Instead of the absolute priority given to large-scale energy production, the multiple possibilities for use of the reservoir should be reinforced. Activities such as aquaculture or navigation might be improved in order to create new sources of income and employment for local communities.
- c) There is a need for institutional support of the EIA process, which should not be the exclusive responsibility of the proponent. Coordination between proponents and governmental agencies at national and local levels, and the creation and reinforcement of regional and local institutions able to contribute to the EIA process is essential for the adequate implementation of the results.
- d) There is a need to develop appraisal methods and criteria adapted to the local needs and resources, and to the available technical expertise and managerial skills and conditions. This points also to the importance of training that should be promoted at the technical, scientific, community and managerial levels, in order to improve local capacities for environmental analysis and management.
- e) An effective participation of the social groups concerned by the project is also crucial, from the early stages of project appraisal. Public participation may contribute to conflict negotiation and settling, and may also be a source of information about environmental conditions and societal perceptions of these conditions. The support of various forms of community participation in the appraisal process, and the enhancement of public awareness of the ecological, technical, socio-economic and political consequences of private and public decisions and actions should be strongly encouraged.

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PAPER 36

HYDROPOWER DEVELOPMENT IN SOUTHERN BRAZIL: REQUIREMENTS FOR SOLVING CONFLICTS AND PROMOTING SOCIAL BENEFITS

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Abstract

The present Brazilian methodology to assess the environmental impacts of hydroelectric systems is briefly described and the evolution of thought on the subject is commented with emphasis on social aspects.

The authors describe the methodology used in the study of electric power potential of the Brazilian reaches of the Uruguay River Basin (75 300 km²) carried out by ELETROSUL, a federal power agency in charge of generation and transmission of electric energy in Southern Brazil, between 1977 and 1979. The master plan for hydropower development (9 459 MW) was selected amongst project alternatives, bearing in mind social, ecological and economic impacts.

The results of this study are commented and the reactions of the communities affected by the implementation process of some selected projects are discussed. A critical analysis is included of the problem with proposals for future action in the basin. The problem is not the classical conflict between water users with different and opposite interests that arise with multiple-purpose projects, but a problem resulting from the lack of planning for integrated use of natural resources - specially land and water - to enhance the pre-existing regional socio-economical potential as a whole.

1. Introduction

The Brazilian legal and engineering procedures to harness its hydropower potential comprise five main stages that take at least ten years to complete from the first site reconnaissance to commissioning the generating facilities.

At each of these stages - reconnaissance, inventory, feasibility, basic project design and construction - the objective is to progressively refine the pertinent technical and economic criteria in order to select the best projects among several possible alternatives and to optimize the site selection, size and characteristics of the selected projects to be implemented.

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Although the systematic studies of hydraulic resources in Brazil started in the early sixties, standard guidelines for the development of master plans and hierarchical selection of projects were established in a series of manuals published during the last 10 years by the federal holding agency - ELETROBRAS. These manuals incorporate the experience accumulated in the process of supplying the fast growing electric power market in the country by constructing large plants of which Itaipu (12 600 MW) and Tucuruí (8 000 MW) are the most recent and impressive examples.

The consideration of environmental aspects, however, has usually been over-simplified and occurred in the later stages of the implementation process. This fact may be due to three main reasons: a) the inability to acknowledge the environmental aspects; b) the lack of technology to correctly assess future impacts eventually caused by those projects in a very dynamic environment, c) the difficulty of dealing with institutional problems in order to develop appropriate solutions and mitigating measures.

This paper describes an attempt made by ELETROSUL to incorporate the environmental aspects, as objective decision variables, since the early inventory study stage that led to the Uruguay River Basin Hydroelectric Master Plan. The studies were carried out between 1977 and 1979. Some of the selected projects have been recommended for implementation within the next years but the start has been hampered by a series of political and economic difficulties, among which was the strong opposition of the communities directly affected by those projects.

The Uruguay River study is a good example of the need, beyond technical and economical feasibility, for engineers, politicians and public decision-makers to consider the socio-political feasibility, or in other words, the conditions that public projects must meet to be acceptable to the communities concerned.

The study area comprises the Brazilian sector of the Uruguay River Basin which, as a part of the Prata Basin, extends into Brazil, Argentina and Uruguay.

The area under study is located between 26°30' and 28°30' S and 49°30' and 54°00' W (Figure 1). It drains, generally from east to west, a sub-region of the Southern Brazilian Plateau, on the border between the States of Santa Catarina and Rio Grande do Sul.

2 Hydropower Inventory

Hydropower is by far the most important potential source of electrical energy in Brazil. The idea behind the inventory is to develop master plans for every major basin so that the expansion of generating capacity may be decided on the grounds of technical, economic and social feasibility, on a regional or national basis. As the market grows geometrically and the most convenient and productive sites are developed, the choice of subsequent projects becomes increasingly difficult. The reason is that a large number of smaller projects with higher unit costs are called for, with a corresponding rise in the demand and competition for financial support by the governmental agencies in charge of supplying the market. Hence the importance of such inventories.

The master plan is a valuable tool at the disposal of the nation for the discussion of the alternatives for multiple-purpose uses of its water resources, particularly with regard to power supply when comparing available energy sources, such as hydro, coal-fired or nuclear power plants. In addition to appropriate technology, the key to success depends on

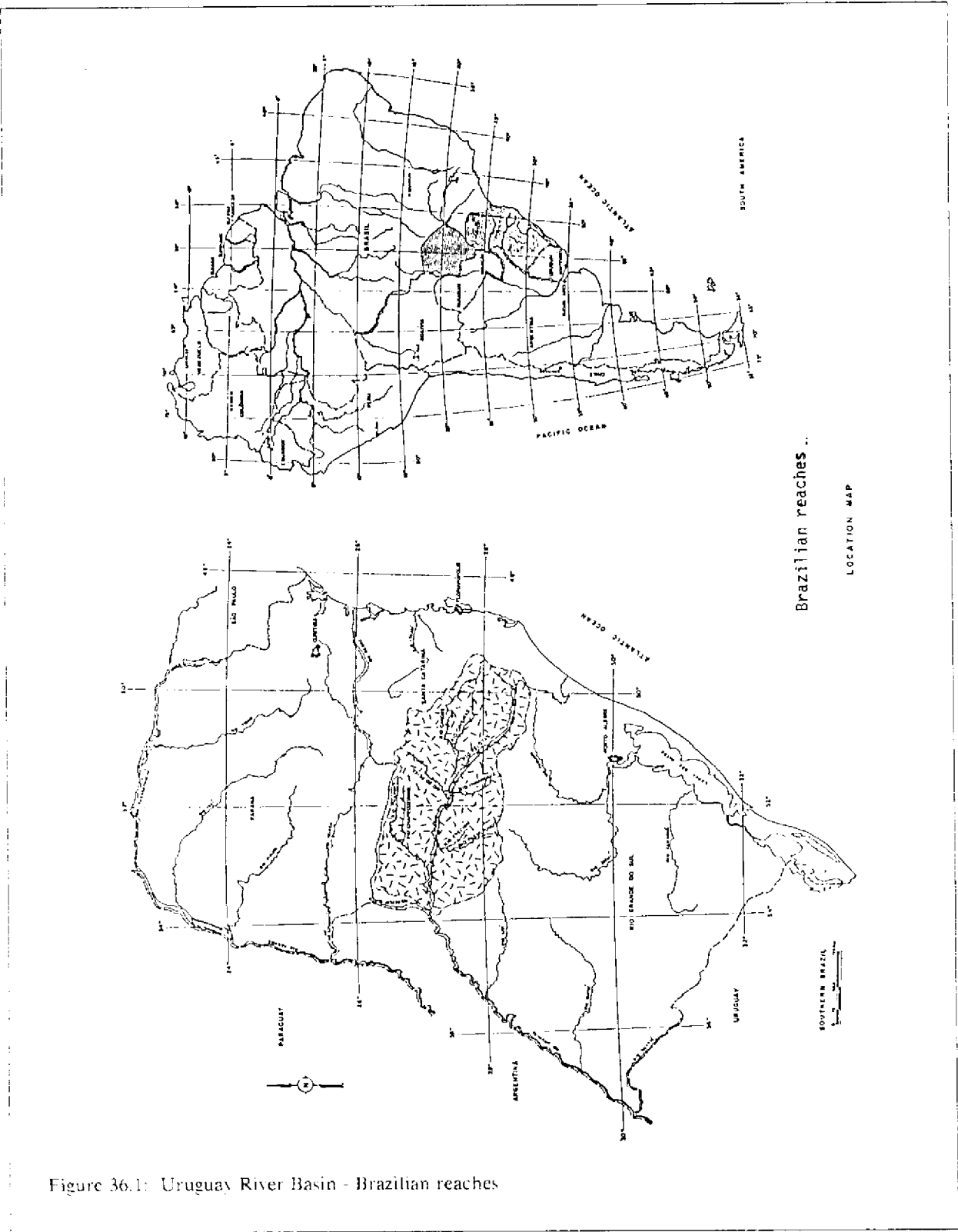


Figure 36.1: Uruguay River Basin - Brazilian reaches

institutional integration among government sectors to develop as comprehensive a plan as possible, and of those sectors concerned with society to make sure that the plan will be as acceptable as possible.

Assuming technology to be the first entry to the problem, it is sufficient to mention the progress made by sciences such as hydrology and hydraulic engineering, systems analysis etc. which provide modern tools to assist with the study.

In this way, the Uruguay River inventory study started with extensive surveying of the topographical, geological and hydrological conditions in the basin in which a set of 51 possible dam sites were initially identified and combined into 16 alternative schemes, each with an average of 20 dams, corresponding reservoirs and power plants of variable magnitude. Costs were calculated and benefits estimated in terms of firm energy and peak capability through deterministic reservoir operation simulation, considering 40-year hydrologic records and market projections and a supply system that included not only the plants being studied but also all thermal and hydro plants supposed to be in operation in an interconnected system sometime in the future.

A good description of this methodology is given by Schwab, Nascimento and Passos including how the schemes were compared in terms of power production at competitive costs with thermal generation, thus resulting in seven basic alternatives for more detailed analysis.

In order to select the final alternative, the studies proceeded along two parallel lines, one focusing on economic and technical aspects and the other on environmental and socio-economic impacts. From the economic point of view, the alternatives were ranked according to the average annual unit cost of power production under different operational conditions of the Uruguay system related to the national interconnected grid, as a function of the initial investment costs, life span and average annual operation and maintenance costs.

From the point of view of environmental and socio-economic impacts, the alternatives were ranked in terms of indices reflecting the greater or lesser magnitude of the expected problems affecting the local population and on the socio-economic activities and organization affected by partial flooding of the territory, as described in the following chapters of this paper.

Institutional integration, as the second entry to the problem, has been more discussed in the literature than observed in actual practice, the reason probably being the lack of coincidence of priorities and interests among prospective users of the natural resources.

In this respect the present case study is no exception, although some efforts were made at the beginning to identify opportunities for multipurpose development of the basin water resources in association with electric power production.

As for public involvement, the country's experience is very limited, one of the main reasons being the several disruptions of the democratic cultural evolution which occurred since the Republic was proclaimed almost one hundred years ago.

3. Environmental and Socio-Economic Impact Analysis

From a previous environmental and socio-economic reconnaissance briefly described in the Appendix, it was found that the portion of the Uruguay River Basin to be directly or indirectly affected by the implementation of the hydropower projects offers:

- a) a significant social and economic activity mainly based on agriculture;
- b) a reasonably interrelated urban network with a few towns located close to the rivers;
- c) Indian reservations and settlements subject to partial flooding by the reservoirs;
- d) extensive deforestation with few remains of the original forest, flora and fauna and
- e) archaeological sites of significant cultural value, along the main river and on some tributaries.

The main scope of the analysis being the comparison of alternatives, it was important to define as explicitly as possible an operational concept of the term "impact", as the effect or modification of the *status quo*. These included all the social activities and cultural values related with the territorial space affected by flooding. It was decided not to express the impact in terms of losses and gains or costs and benefits but rather in terms of relative indices established by consensus within multidisciplinary working groups.

In general, the following assumptions and procedures were adopted:

- variables were identified and selected bearing in mind their significance and representativity and the possibility of quantifying and differentiating them for each alternative;

- data was mainly acquired from pre-existing records and literature, supplemented by field sampling and econometrics surveys;

- computation of impact indices and comparisons of alternatives were made by normalizing and weighing a set of selected variables in a matrix configuration, using a variation of the Delphi Method.

The analysis of the social and economic structures of the study area was divided into urban and rural aspects. The concepts of urbanization and geographical space organization as related to human activities in the region were also introduced in the quantitative analysis in parallel with an assessment of the anthropological, archeological and ecological values.

The results are shown in Table 1 where the variables selected to represent the impacts are expressed with their respective weights together with the manner in which they were combined to produce an impact index for each alternative.

4. Selection of the "Best" Master Plan

Although a thorough description of the analysis procedure is beyond the scope of this paper, it is of interest to examine Table 2 which contains the most important decision parameters that summarize the technical and economic aspects and the social and environmental impacts associated with each of the seven proposed master plan alternatives.

Since all alternatives were considered equally feasible, the comparison for the final selection was based on economic parameters. These were expressed in terms of estimated average annual unit cost of power production under different operational conditions of the

Table 1 IMPACT ANALYSIS (Variables and weights according to DELPHI Panel)

Selected Variables	Weight	Area	Subject	Result
Displaced Population	(0.4)			
Standard of Living	(0.4)	Urban		
Infrastructure	(0.2)	(0.6)	Sociology (0.26)	
Displaced Population	(0.6)			
Flooded Area and Land Property Distrib.	(0.4)	Rural (0.4)		
Flooded Area and Potential Land Use	(0.4)			
Employment Loss	(0.3)		Economy (0.28)	Final Resulting Effect (Alternative Impact-Index)
Income Loss	(0.3)			
Urban Polarization	(0.7)		Territorial Organization (0.21)	
Flooded Area and Number of Counties	(0.3)			
Flooded Area and Vegetation Configuration	(1.0)		Ecology (0.12)	
Flooded Area of Indian Reservations	(0.3)		Anthropology (0.13)	
Tribal Population	(0.7)			

Note: It was assumed that archaeological sites would be equally affected by all alternatives.

Uruguay River System that maximize the amount of continuous or firm energy delivered to the interconnected power system of the South and Southeastern regions of Brazil.

This cost was calculated taking into consideration investment amortization of the plants in 50 years, including all expropriation and indemnization costs, plus the annual operation and maintenance costs according to standardized procedures adopted by ELETROBRAS for this kind of study. The results show that Alternatives V and III rank first and second with respect to the amount of firm energy and unit cost but it is interesting to emphasize that all the alternatives showed unit costs well below the average unit cost of equivalent thermal energy (US\$ 40/MWh).

On the other hand, from the social and environmental points of view, the results reveal that to the best energy-generating alternative corresponds the highest impact index and conversely, to the alternative with the lowest impact index corresponds the least amount of energy at the highest unit cost. As a matter of fact, Alternative I shows the lowest impact index, followed by Alternatives II and III, VI and VII, and IV and V, which, two by two, are virtually equivalent. It is interesting to note that the impact indices resulting from the adopted methodology basically reflect the same ranking of alternatives according to the area to be flooded and/or the population to be displaced, as shown in Table 3. In this connection, for reference purposes, it is also interesting to compare the total flooded area and population with those of Itaipu (1 460 km², 34 000 people) and Tucuruí (2 160 km², 11 000 people).

Examining all technical and socio-economic aspects in more detail, and exploring some possible sub-alternatives, the Delphi Panel made a recommendation in favour of Alternative III which was subsequently approved by the federal authorities.

Later on, the 22 dams comprising Alternatives III were ranked for implementation. The feasibility studies proceeded focusing on the five most economically attractive projects; two were scheduled by the last Government for implementation on a short-term basis. One of them is now ready for tenders, whereas the other will soon attain this stage. A third project was recently included in the implementation schedule.

5. Public Involvement and Reactions

During the seven years that elapsed since the alternative master plan was selected and approved, public reactions have gradually changed from a moderately cooperative mood which prevailed during the early stages of the study to a widespread mobilization in the region against the construction of any project in the study area.

The public involvement was strongly influenced by a series of political events that characterized the transition to democracy experienced by the country during the same period. However, at least three stages of reaction have been identified by social scientists (Sigand 1985, Sherer-Waren 1985) as a result of the actions - or the lack of them - undertaken by the Federal Government, in general, and by ELETROSUM in particular.

The first stage of direct public involvement was characterized by the demand in the late seventies for fair compensation and firm assurance as to when it would be paid. As an alternative to compensation, resettlement on equivalent fertile land was considered as an acceptable solution, particularly by those who worked on the land but did not legally own it. However, the Brazilian experience in this respect is not consistent, regardless of the nature of the public works (dams, roads, industrial areas, urban developments, etc.) and there are examples of unresolved or pending legal disputes that are detrimental to the credibility of the Government.

Another important fact which occurred during this period was the foundation and organization of the Regional Commission of People Affected by Dams (CRAB), inspired and assisted by the Catholic and Protestant Churches, rural workers' leagues, regional universities and politicians belonging to opposition parties. This commission was supposed to lead the discussions within the affected groups as well as the negotiations with ELETROSUL which, in the meantime, established and published a compensation policy to be applied as soon as funds were allocated for the construction of the proposed projects.

Table 2 MAIN DECISION PARAMETERS

Variable Alternative	I	II	III	IV	V	VI	VII
Case 1:							
Firm Power (MW)	1870	2 550	2 670	2 740	2 780	2 480	2 550
Ref. Capacity (MW)	5 050	5 250	5 290	5 240	5 260	5 200	5 380
Total Inv. (US\$M)	4 400	4 747	4 810	4 866	4 937	4 589	4 686
Unit Cost (US\$/MWh)	30.30	23.90	23.70	22.90	22.80	23.80	23.70
Case 2							
Aver. Power (MW)	3 390	3 750	3 790	3 770	3 860	3 660	3 640
Inst.Capacity (MW)	5 990	6 680	6 740	6 730	6 820	6 450	6 510
Total Inv. (US\$M)	4 665	5 072	5 156	5 170	5 261	4 840	4 925
Unit Cost (US\$/MWh)	25.00	23.20	23.00	23.20	22.80	23.10	23.60
Impact Index	0.48	0.64	0.65	0.97	1.00	0.84	0.88

Cases 1 and 2 were devised for sensitivity analysis of future operational conditions:

Case 1 : Isolated system

Case 2 : South-Southwestern interconnected systems.

The second stage coincided in the early eighties with the peak of population displacement in connection with the Itaipu Project where, in spite of the fact that indemnities were higher than the current land market basis, these were considered as unsatisfactory by those involved. The main objections were the sudden rise of land prices in the vicinity, the inability of some people to deal with large liquidities, the tendency to quick spending and the frustration of an improved standard-of-living expectation.

As a consequence, the communities in the Uruguay River Basin started to demand land exchange in the same region, since resettlement offered by the Government in newly-opened federal land in the country's Northern region as was also open to question, specially by those who had experienced it.

Opposition to the proposed dam projects grew with the announcement that the first construction activities would begin. Among other related psychological factors, the public seemed to fear that a *fait accompli* would jeopardize its capacity to react. However, recession and persistent lack of funds led to successive postponements of the construction work which aggravated the social stress even among those who sporadically had spoken in favour of the project implementation.

Table 3 AREA AND POPULATION AFFECTED BY ALTERNATIVE MASTER PLANCS

Altern. no.	Total Flooded Area km ²	Potential Usable Land km ²	Population			Total
			Urban	Rural	Tribal	
I	920	564	2 880	15 000	670	18 550
II	1 460	830	2 150	25 700	720	28 570
III	1 525	846	5 890	29 300	720	35 910
IV	1 830	940	18 960	36 100	800	55 860
V	1 870	940	18 960	39 500	815	59 275
VI	1 520	8856	15 890	27 300	800	43 990
VII	1 560	856	15 890	30 500	815	47 205

Note: It was estimated that 33 percent of the population would have to be relocated.

By 1983, public involvement entered its third and more radical stage expressed by the slogan "stop the dams" and by an intense mobilization not only of those directly affected but also of a large portion of the regional population to whom it had become clear that the problem was nothing but the emerged part of a political iceberg with a very extensive range of connotations.

The demand for a democratic government, for participation opportunities and the fulfillment of other high-level social objectives became matters of daily concern together with unemployment, inflation, land reform, etc.

In practical terms increasingly large population segments started to question decisions made solely by governmental agencies. In particular, with reference to the Uruguay River hydropower development plan, a conflict emerged between ELETROSUL, seen as part of the Federal Government, and the communities that would be affected by the reservoirs.

This stage culminated with the collection of one million signatures at the foot of a manifesto conveyed by CRAB to the federal authorities requesting cancellation of all proposed projects. Some violent episodes were also recorded in the field between the local population and ELETROSUL representatives.

In 1985, the new Federal Government decided to halt whatever was being done in the field except for the relocation of a small town situated within one of the future reservoirs. That activity had been undertaken independently of any dam construction work as a result of a very effective lobbying by a commission formed by the local community. This

commission remained as one of the only two communication channels still open to the public in the area; the other was a much larger commission that despite being totally in favour of the immediate implementation of the first proposed project, was not as effective in negotiating with the opponents to the project.

At the beginning of 1986, in response to a renewed request by CRAB and by ELETROSUL, the Federal Government decided to form two commissions with representatives of all the parties involved in the conflict in order to discuss ways of mitigating the social problems raised by the future dams and to propose compensatory measures to be implemented as the projects proceeded.

6. Critical Review

The Uruguay River hydropower development study demonstrates very clearly that public works projects must have their socio-political and environmental feasibility clearly demonstrated at critical decision instances, with the same degree of relevance as for the traditional technical and economic feasibility studies, no matter how economically attractive they may be.

Learning from the past requires a critical review of the whole process to discover what has been overlooked and devise corrective measures for the future

Some findings generally coincide with what has been pointed out elsewhere (Monosowski, 1985), nevertheless, they will be briefly described as a basis for the discussion of the proposed requirements for solving the conflicts that have arisen in the present study case:

- the intrinsic value of an abundant energy supply has never been questioned within the technical group, or in other words, there was an implicit assumption of the social consensus as regards the need for the projects;

- the "no-go" alternative should have been included in the analysis as an absolute reference of minimum impact at the regional scale; the difficulty being to quantify the required trade-offs on a national basis.

- in addition, a reference to acceptable mitigating measures should also have been established in advance, as a means to quantify the trade-offs on a regional scale. As mentioned early in this paper, all the electricity produced by the new projects would be delivered to the interconnected system. Due to legal constraints, this arrangement does not allow for any kind of compensation to those displaced by the projects other than for flooded properties;

- the study emphasized the impact on the *status quo* where as a prospective analysis would have been important as a means to evaluate future mitigating or compensatory actions, taking into account potentially positive effects and that the implementation of the 22 dams would be a long process;

- although many aspects other than the purely engineering ones had been considered, the results basically reflected the point of view of the governmental sector in charge of electric power supply. A better understanding of its own role in a broader framework would perhaps have led ELETROSUL to seek a greater involvement with other public agencies in the decision-making process, at the federal and regional levels.

It is not clear to the authors whether systematic and open public involvement would have been possible in the earliest study stages due to cultural, political and institutional constraints; however, the participation of other public agencies and representatives, for example in the discussions within the Delphi panels, as well as the participation of experts with field experience in the study area is now regarded as essential for the identification of the subjacent social problems which emerged later;

- in connection with the methodology strictly speaking, it is thought that a sensitivity analysis of resulting impact indices with different sets of variable weights would have disclosed possible bias introduced in the process, such as the occasional over-emphasis put on flooded areas and affected population in the identification and weighing of representative variables, as pointed out before. Notwithstanding the fact that the Delphi process implies a recursive sensitivity analysis, carried out in advance, results should be carefully appraised by independent experts before a final recommendation is made. Ideally, this would mean having as comprehensive a Delphi Panel as possible. In practice, however, it may prove to be very difficult and time-consuming to work with such a large multidisciplinary group;

- in view of the above considerations, there seems to have been a false sense of confidence in the application of a multidisciplinary methodology, since the recommended master plan alternative should not have been taken as the best one, as ELETROSUL's officials claimed in public addresses that followed governmental decisions regarding the implementation of the first dams in the area;

- the lack of an institutional and regular communication system, as well as of consistent information, was probably the main cause of the credibility erosion suffered by ELETROSUL at the time. It was clear that this point was crucial, but neither the Government nor ELETROSUL were able to deal with it in an efficient way;

- in the author's opinion, for example, there was a serious communication blunder in the announcement of the 22-dam master plan at the time that the Itaipu impacts were at their highest. It was never made clear to the public that in the Uruguay Basin the impacts would be considerably less important, since for about the same total flooded area and population as at Itaipu, the implementation process would take much longer, with plenty of opportunities for monitoring the re-adjustments.

Finally, it is evident that the decision to implement any one of the 22 projects should have been made on the basis of specific environmental impact assessment, including proposals for mitigating and compensatory measures with clear statements regarding timing, responsibilities and funds sources.

7. Requirements for solving conflicts.

When analyzing the government's role in a society, its responsibility for the mobilization and organization of the social forces for the satisfaction of the needs and objectives of that same society seems to be generally accepted as the essence of political activity. On the other hand, the rational use of the nation's natural resources and the equitable allocation of benefits and costs among all citizens may require a very special ability to translate correctly those needs and objectives into engineering objectives. In reality those needs and objectives are usually connected with, or somewhat hidden by, all sorts of anxieties generated by social dynamics.

The need is then established for close cooperation between political and engineering actors, as has been discussed in the literature pertaining to either field of activity. No matter what the political regime, however, it should be pointed out that public opinion plays a highly important role in the decision-making process.

Kuiper (1971) explained this concept on a feedback diagram and the worldwide argument over an assortment of projects that have failed to meet social and environmental standards and goals stresses the need for a continuing effort, in this direction.

It is also interesting to note the role of international financing agencies in the specification of guidelines and project analysis procedures where attention is drawn to the need that projects supported by them do not hamper sustainable development and sound environmental policies.

Besides, when wisely used the resources required for the implementation of large projects may induce immediate chain-reaction effects to the benefit of communities not directly involved in the process, such as those resulting from provisions for the enhancement of the regional infrastructure to support the construction activities.

In the Uruguay River case study, it is recognized that there exists an opportunity to solve the conflicts, provided that:

- the water resources development planning for power generation be integrated with the use of other natural resources available in the region, among which arable land is the most relevant one. Indeed, there is presently a demand for a land reform in the whole country. A more equitable land distribution and support to qualify land workers in the use of suitable technologies are perceived as extremely important factors of social well-being. This fact has an immediate influence in the Uruguay Basin since the implementation of the power scheme will certainly increase the demand for agricultural land in the region;

- the implementation of hydropower projects takes into account the need for mitigating and compensatory provisions to be established through cooperative planning and negotiation with the communities involved;

- such mitigating and compensatory provisions be conceived within a regional development framework to allow for direct and permanent benefits to those communities, not only to ascertain the replacement or the continuation of the socio-economic activity but also to open new development opportunities that will ultimately help to overcome some historical causes of poverty in the region;

- the implementation of projects be coordinated within a multi-institutional framework, both public and private all the parties accept to share equal responsibility to bring their tasks to a successful conclusion, including permanent monitoring for possible adaptations of the "design criteria";

- this strategy be fully transparent to the public through permanent communication and clearly stated goals and objectives.

8. Perspectives

In 1987, the country will have a new Constitution as the last stage of the present political transition period. Several issues of paramount importance, related to the subject of this

paper are already being discussed and hopefully will set a new basis for public involvement in the decision-making process regarding large public engineering projects. The environment will most likely be included in the Constitution as a legally protected entity.

As a matter of fact, the National Environment Council has recently passed a Resolution which stipulates that every activity or project potentially affecting the environment must be subject to licensing, with an environmental impact statement (EIS) required for public information and eventual discussion.

In this connection, the critical review of its activity in the Uruguay River Basin has led ELETROSUL to carry out a comprehensive study not only to better assess future reservoir effects but also to formulate mitigating and compensatory proposals within a regional framework to be discussed with the affected communities through the official commissions early in 1986.

Besides the official acceptance of CRAB as legitimate interlocutor, this has made it possible to resume negotiations, since participants from urban and rural areas will hopefully contribute to overcoming a near deadlock.

Of course this will not do away with the need for multi-institutional integration. On the contrary, once those proposals are discussed and accepted by the interested parties, they should induce coordinated action by decision-makers at all levels. Coincidentally, recent negotiations with an international financing agency, whose largest loan ever granted to Brazil will be partially used in the implementation of the Uruguay River power plants, included a clause by which the country is committed to removing institutional barriers and allocating funds to implement those mitigating and compensatory measures.

At the technical level, the Uruguay River hydropower development study is now looked upon as an example to be followed in connection with similar studies underway in the country, particularly with regard to the association of engineers and social scientists to produce better plans than those produced otherwise.

Nevertheless, caution is needed since almost ten years were lost in learning what should be done, but how the procedures will actually evolve is a further challenge.

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Annex

The Study Area

Physical Aspects

The study area comprises the Brazilian reaches of the Uruguay River Basin which as a part of the Prata Basin extends into Brazil, Argentina and Uruguay territories.

The area under study is located between 26°30' and 28°30'S and 49°30' and 54°00'W (Figure 1) and drains generally from east to west a territorial sub- region of the Southern Brazilian Plateau on the border between Santa Catarina and Rio Grande do Sul with a total surface area of approximately 75 300 km² of which 46 300 km² are in Santa Catarina and 29 000 km² in Rio Grande do Sul.

The main tributaries of the Uruguay River Basin have their headwaters at an altitude of about 1 200 m above sea level and the total available head up to the Argentine border is about 1 000 m. Two types of well-defined morphology are easily recognizable in the region: the first, in the upper portion, has mild slopes with tabular or undulating surfaces; the second, more widely spread in the Basin, presents variable relief from gentle, at the top of the plateau, to steeply undulating close to the main drainage ways, with different levels of dissection.

The predominant geological feature is a sequence of basaltic lava flows with sedimentary rock formations in the upper region.

The courses of nearly all the rivers result from discontinuous and greatly altered regional fractures, some possibly being associated with extensive faulting.

Mineral resources are of little importance. A few amethyst mines and some thermal spas are of relative regional importance. Copper, limestone, rare earths and aluminum were also found to be sporadically present, but as only scant research was carried out in the region, it is difficult to assess their economic value.

Of interest to understand the prevailing social and economic organization in the area is the fact that the soil cover is generally not very thick, except in the upper portions close to the plateau region. As a rule, the greatest soil thicknesses are found at the convex margins of river bends which show evidence of human settlements since long before the arrival of the first European settlers in the eighteenth century.

The climate is of transitional or temperate type whose predominant genetic factors are the mobile polar anticyclone of South America and the maritime tropical anticyclone of the South Atlantic. Temperature variation is basically determined by the relief of the basin as well as by the continental factor, gradually increasing from east to west, from annual averages of about 11°C in the plateaux to 20°C near the Argentine border. The seasons tend to follow the pattern of the southern hemisphere temperate zones with the highest temperatures in January and the lowest in July.

Annual average precipitation is over 1 400 mm throughout the basin but there are no clearly defined wet and dry periods. Besides, the narrow and deep valleys combined with steep slopes, a high degree of deforestation and thin soil cover, are relevant physiographic characteristics that impose a very high variability to the streamflow pattern of the basin.

Average flows are of the order of 20 lkm⁻² but exceptional floods may exceed 1 000 lkm⁻²

Under such conditions, hydropower development requires artificial regulation through dams and reservoirs which implies higher costs, besides inundating the most fertile land areas in the low portions along the river valleys. This is probably the reason why the basin potential remained mostly undeveloped as only one sizeable plant (Passo Fundo 220 MW) had been built in the area before the studies began in 1977.

Waste disposal from paper mills along with chemical products used in agriculture have already given rise to serious concern along some stretches. Sedimentation is deemed not to be as serious in spite of inadequate agricultural practices in most areas.

Social and Economic Aspects

The study area is a largely agricultural region, subdivided into 137 autonomous political-administrative units with a population of 2.5 million inhabitants with a basic infrastructure which reasonably meets their needs though not uniformly. Practically all population centres have mail and telegraph services, television reception and radio stations. Integrated electric power distribution is considered to be the item of infrastructure with the highest service rate (79.4%) while basic sanitation is the most deficient at present, especially the sewage collection and disposal systems.

The cities, though not representing a perfectly integrated system, tend to have a balanced distribution regarding size, but present a very uneven spatial distribution of county seats. In the east there is a predominance of large holdings, with small capacity for the absorption of manpower; while in the west there is a predominance of smallholdings, generally associated with subsistence agriculture, a fact that could explain the greater density of population in this zone.

Seven towns of 15 000 to 120 000 inhabitants linked by first class federal roads have become centres of attraction for the surrounding communities. They stand out because of their basic infrastructure, as well as for the availability of equipment and urban services.

Most of the population in this region is concentrated in the rural area, which is undergoing an urbanization process. The majority is composed of young people, and in all age groups there is a balanced proportion of both sexes. The literacy rate is comparatively high, although the level of schooling is rather low.

The growing of soyabeans, which comprises 32 percent of the total value of the primary production sector is the major agricultural activity in the region, followed by the growing of maize and the raising of pigs and poultry, which comprise 23 percent and 16 percent of the agricultural output respectively.

The fairly recent discovery of the region's agricultural proclivity, especially after the advent of the soyabean in the 70's, has greatly and progressively encouraged the occupation of the area for agriculture. The deforestation of the original vegetation has eliminated major

habitats and has severely jeopardized the survival of the remaining fauna. Agriculture uses about 34 percent of the total area and pastures 38 percent. The remaining natural vegetation is only found in the basin in small, scattered areas, except for a few areas protected as forest reserves.

Of all the economic sectors, it is the industrial activity, with a predominance of small enterprises, that has shown the greatest recent expansion, especially those related with exporting pork and chicken products. The services sector, second in economic importance, is totally influenced by the others, involving the marketing of local products as well as providing the population with supplies.

Indian tribes, the Kaingang and Guarani, inhabit the area under the protection of the federal agency FUNAI, either on reservations or scattered as small family groups. The existence of several archeological sites of various cultures has been recorded, some with and others without pottery.

PAPER 37

DECISION SUPPORT SYSTEMS FOR MANAGING LARGE INTERNATIONAL RIVERS

G. Kovacs

1. Scope of the Project

The best way to visualize the scope of the project is to analyse the reasons for selecting the three elements in its title:

- why are large and especially international rivers being investigated?
- What types of management activities should be analyzed?
- How can the planned systems be used to support decision-makers?

Large rivers are indispensable natural resources and valuable environmental components. Their role in both global and national economies is important for several reasons: (i) they are continuously supplying renewed resources for the water consumption of communities, industry and agriculture. (ii) Their existence provides conditions for utilizing the water in the river bed, such as recreation, fishing, hydropower generation, transportation. (iii) They are receiving, transporting and assimilating the greater part of the wastes produced by human activities as they are the direct recipients of sewage effluents. (iv) Apart from disposing of this direct load, large rivers also serve as sinks for several environmental disturbances because the products of erosion, airborne and other non-point source pollution finally reach the rivers at the final stage. The environmentally sound management of the water resources of large rivers is, therefore of paramount importance.

At the same time there are several serious conflicts between the different interest-groups using a river: those whose activities may considerably alter the quantity and quality of the available water resources (mining, urbanization, intensified agriculture, deforestation, etc.) environmentalists opposing expected changes in the present conditions of rivers due to proposed water management activities, and ultimately between the various users themselves who want to utilize the water from the river. In the last group the question of priority and the validity of earlier licences arises, when the available water is limited, but the most severe tension may occur between upstream and downstream users. Figure 1 shows an example of how the mean annual discharge decreases and the salt concentration (especially the sodium content) increases along a river due to irrigation, making the water unfit for irrigation further downstream.

The conflicts can be eliminated only if the water management policy is harmonized with the activities of other sectors of the economy, and, if development trends in the whole basin

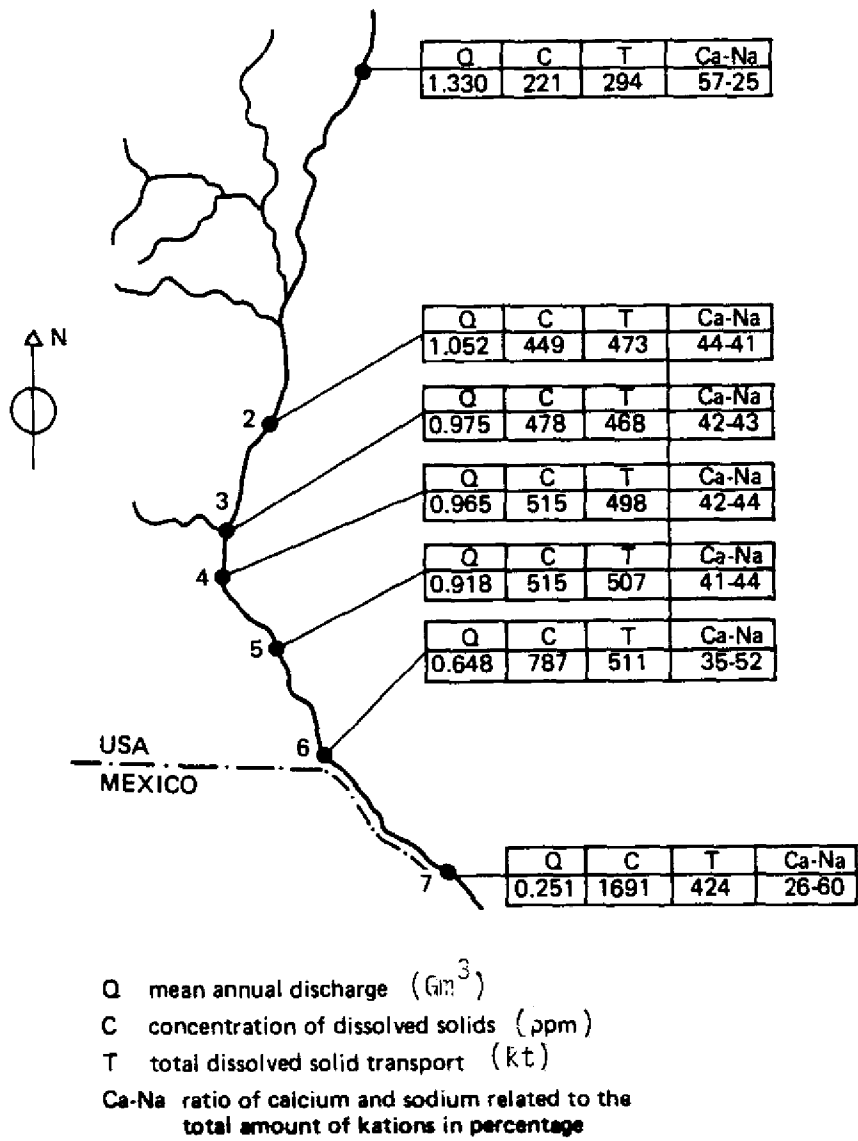


Figure 37.1

are considered. The latter task may raise more serious problems when the basin is divided into jurisdictionally different units and especially by international boundaries, which is why large international river basins deserve special attention.

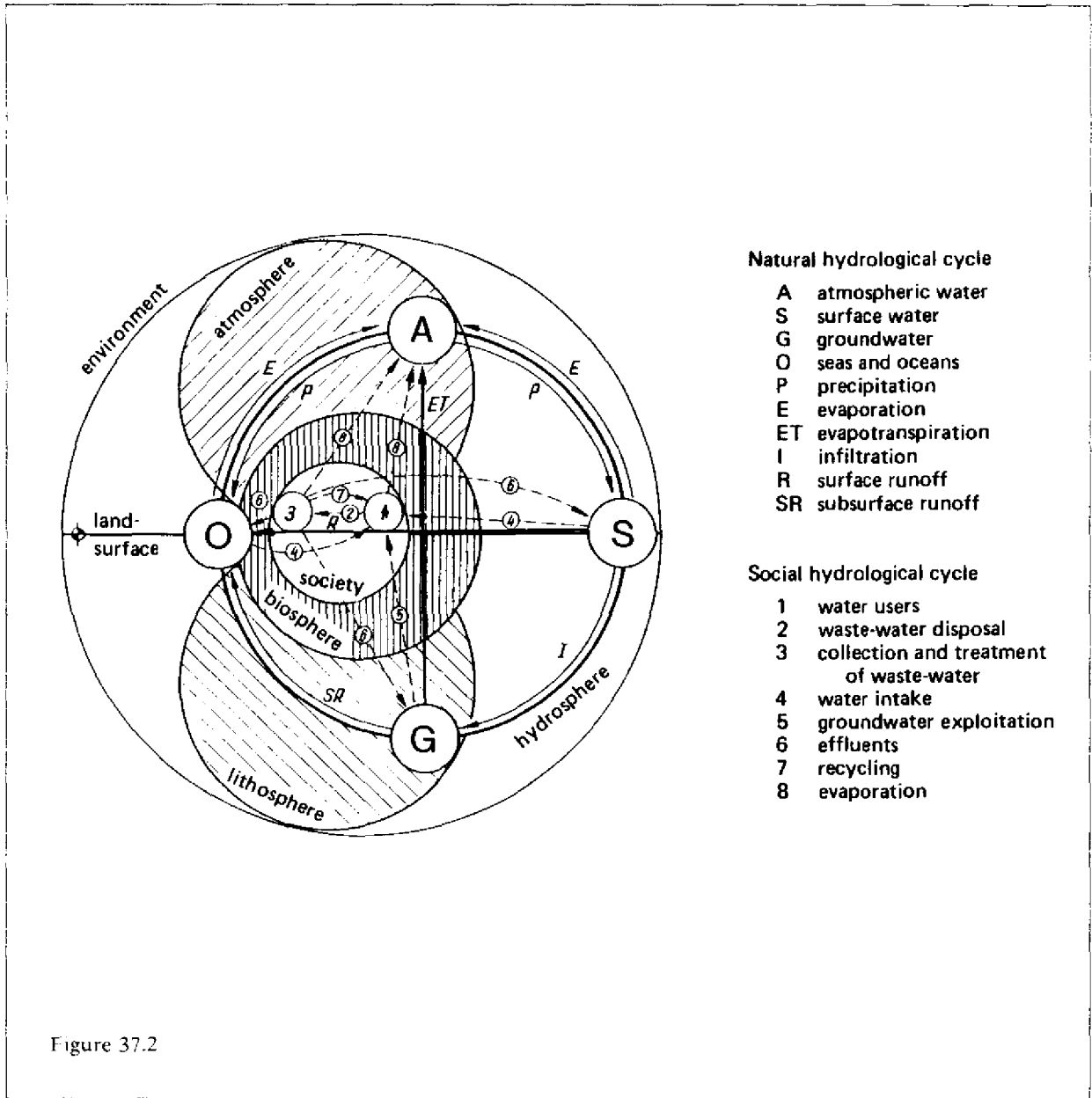
The hydrosphere - due to its continuous movement - interconnects the other spheres of the globe. The relationships become more complicated when the anthropogenic hydrological cycle is also considered, separately from the natural cycle (Figure 2). The processes determining the availability of water in these systems either by limiting its amount or by influencing the quality should be analyzed. The natural processes are either physical (characterized by the elements of the hydrological balance), chemical (like solution and precipitation of chemicals or oxidation and redox processes) or biological (influenced by terrestrial and aquatic ecosystems). The anthropogeneous effects modifying the natural processes can be divided also into three groups:

- the influence of the different forms of land use (rain-fed and irrigated agriculture; forest management, e.g. clearing forests here and reforestation elsewhere; urbanization; development of industrial areas; mining)
- the control of runoff either by means of reservoirs and water transporting systems, or by modifying runoff conditions in the river bed (flood control, river training, construction of barrages);
- pollution of water coming either from concentrated or dispersed sources and originating from households, industry, agriculture or from any other human activities (organic and inorganic pollution, toxic wastes, heavy metals, thermal pollution, etc.).

The main conclusion drawn from the list of factors influencing the water regime both quantitatively and qualitatively is that the investigation of water management activities does not provide sufficient information on the expected behaviour of large rivers. Any change in land-use within the basin may have considerable impact on the hydrological cycle and similarly the applicability of a given form of land use may depend on the availability of water. Therefore it is necessary to recognize that land and water management are closely interrelated activities and that the policy determining the main directions of their development should be formulated in an integrated system. Hence, the answer to the second question in the opening paragraph above is that the field of influence of the project covers all types of management activities within the basin which may alter the water regime directly or indirectly and the planned decision support system should provide information for the joint policy formulation of land and water management.

To answer the question as to how decision-makers can be supported, a quotation selected from a synopsis of the World Conference on Large Lakes (Mackinac, 1986) is relevant: "The huge mass and diversity of environmental data overwhelm our ability to comprehend their meaning. Computer-based data and information management systems are needed to structure and organize this mass of information, so that it becomes immediately useful to decision-makers." Hence, the requirement is to provide integrated information in an easily understandable way on both the present conditions of the basin and the changes expected due to various management policy options.

The characterization of the present conditions requires the construction of a data-base management subsystem. The task of this subsystem is to produce information at any hierarchical level starting from the collected primary data and ending at the most aggregated form giving only some important quantitative and qualitative parameters of both the water



and the ecosystem. The harmonization of data collection and processing, the selection of variables representative at different hierarchical levels and the way of communication are the questions to be answered when constructing this subsystem. Attention should be given also to the fact that the availability of data, as well as geographical and socio-economic conditions also influence the structure of the data-base management system. Therefore, the subsystem has to be adaptive to local conditions.

The purpose of the other subsystem is to predict the expected consequences of planned management policy actions. Obviously, details of several models for impact assessment have already been published. A common feature of these models is that they tend to capture

many aspects of the processes modelled and therefore have a great degree of detail. For the construction of a decision support system for large basins these comprehensive models cannot be applied directly because when using a large-scale, the structure of the models becomes very complicated and the data required for the solution of the models are usually not available for all small parts of the basin. It is also necessary to consider that the decision support system does not solve the problems automatically, although it gives answers to the questions of decision-makers in the analysis of regional management policies. This dialogue requires a simple method of operation and relatively fast responses but the computation time would be too long if comprehensive models were used as a subroutine of the system.

Considering all these aspects, the intention is to utilize the decomposition- aggregation approach, i.e. to study detailed processes mostly using existing models and to integrate the results for large units simplifying the presentation in this way. Hence, the final goal is to construct hierarchical systems of models which can predict the expected consequences of different policy options in land and water management at various levels of decision- making with desired accuracy and with a suitable degree of aggregation in space and time. Naturally, in the construction of this subsystem the geographical and socio-economic conditions should also be considered, and the results should be communicated by the same graphical display as the data-base.

2. Background and Objectives

The Large International Rivers project is a natural continuation of the research performed at IIASA during the past years dealing with various water management problems of different hydrological regimes and under different geographical and socio-economic conditions such as the Tisza and the Vistula Rivers, shallow lakes, the Skane project, etc.

It is a direct follow-up of a recently completed project producing decision support systems for the analysis of regional water policies (Orlovski et al.: Final Report of Collaborative IIASA project "Regional Water Policies", WP-86-33, IIASA). In the preface of this final report, the objective of a decision support system and the role of systems analysis in its construction is explained. "The arsenal of devices and principles used by systems analysts includes varieties of formal and informal methods (logic of reasoning, common sense, data processing, formal mathematical methods, use of computers, etc.). It is always important to find a good synthesis of these formal and informal tools and to design a computerized system as a qualitatively new tool for the analysis of concrete problems pertinent to a specific system under study. And, if such a system is designed as a tool to assist decision-making focussed at resolving these problems we call it a decision support system. To our understanding this problem of synthesis or design is the focal point of systems analysis".

This basic philosophy of constructing a decision support system is preserved also in the present project. There are, however, several points where the objectives of the Large International Rivers project differ from those of the Regional Water Policies project.

The main difference is that of scale. The size of regions investigated earlier was less than 1 000 km². In such a unit it is relatively easy to determine which economic sectors - and which types of activities in those sectors - make the most significant impacts on regional water systems and through them on other parts of the environment within the region. The natural processes through which these impacts take place and the negative feedbacks of the impacts on the quality of life can also be recognized. The findings are then summarized in an impact diagram, which is a formal representation (a model) of the region investigated, and provides the backbone of the decision support system. In a large river basin there are,

however, so many influencing factors that such impact diagrams are very complicated. It is advisable, therefore, to build up the system from modules, each used to investigate the impacts of a given type of action of land and water management, and integrate the results in the final stage.

In the definition of decision support systems quoted earlier, the analysis of concrete problems pertinent to a real system was also emphasized. Two specific regions were selected by the Regional Water Policies project (the agricultural region of Southern Peel in the Netherlands and the opencast lignite mining region of Lusatia in the GDR), and the decision support systems were constructed separately for the two areas considering the local geographical and socio-economic conditions. However, it is required that the results of the Large International Rivers project should be applicable for the analysis of various international river basins. This goal can be achieved only if its general character is preserved without making any assumptions *a priori* concerning the local conditions. Again, meeting this demand is assisted by applying the compatible modular structure. In analysing different case studies, the modules relevant to the basins being investigated will be prepared. The system will remain open, in this way maintaining the opportunity to insert new modules where and when necessary. The case studies will also assist in selecting some important activities among the numerous possible options of land and water management policies to be analysed in the first phase of the project.

In the previous project, two different levels were distinguished in the hierarchy of decision-making: the upper level combined the policy-making authorities and the lower one the users. The modelling structure was constructed by considering the requirements of the upper level. The first stage is the scenario analysis to determine the trajectories of further regional development which are satisfactory from economic, environmental, social and other aspects. The second stage (policy analysis) is an investigation of the feasible regulation policies influencing the behaviour of the lower level decision-makers in a way that a development close to the projected trajectory can be realized. The modelling in the scenario analysis is further decomposed into two levels: (i) a fast screening of feasible planning decisions by applying simplified models and long-term steps (usually one year or longer), and (ii) simulation of management strategies when the seasonal variation and the random character of uncontrollable variables as well as the possible counterbalance of random events by operational rules are also considered.

When investigating large international rivers, the initial hierarchical level of decision-making has to be raised partly because of the larger scale and partly because of the international character. This can be achieved by distinguishing, in the upper group of decision-makers, a government level (responsible for major decisions especially in international cooperation) and a regional level (responsible for implementation of decisions in the region). Obviously, the hierarchy of the model systems should be modified accordingly. At the highest level only simplified models suitable for screening the most important policy options are needed. The requirements of authorities implementing the decisions in the regions are not changed; hence, those persons can use the scenario analysis and the simulation of management strategies as was explained earlier. At this large-scale and also considering the international character of the basin, it is advisable to perform the policy analysis separately. Hence, the Large International Rivers project does not include this step in the decision support system.

The enlargement of the hierarchical system and the larger scale to be investigated combined with the limited resources and time available for the execution of the present project impose some restrictions on its scope.

The most important limitation compared to the Regional Water Policies project is to restrict the modelling to the prediction of the expected scenarios in large river basins as results of different management policies using only technical terms. It is not required, therefore, to conduct detailed socio-economic impact assessments or perform cost-benefit analyses, but rather to focus on the scientific assessment of potential environmental transformations. Consequently, the indicators used to evaluate the various trajectories describing the results of different management policies applied in the basin and expressing the expectations of the policy-making authorities cannot be fixed in monetary terms but only at some limit values of the state variables.

This limitation is in harmony with the character of the project. It should be considered that the preferences based on multiple economic, environmental, social and political concerns can never be fully formalized even by the policy-making authorities themselves. To set up a predetermined targets would be especially difficult in international basins shared by countries having different socio-economic structures. In such basins even the indicators expressed in monetary terms might be meaningless. It is expected, however, that the formulation of management policy is an iterative process, where a dialogue develops between the decision support system and the decision-maker. In this way the policy-making authorities become active participants and can evaluate the results of the system directly.

It is possible, at a later stage, to supplement the system by models considering socio-economic conditions and consequences as well. The ongoing project dealing with the problems of conflict resolution in international river basins executed by the George Washington University (USA) with the support of the Ford Foundation provides a good opportunity to select the most important socio-economic aspects to be considered supplemental to the Large International River project. Utilizing the results of that project the models evaluating allocations, benefits and environmental values can be constructed. These models, however, cannot be general; they have to consider always the local and instantaneous conditions.

Another type of limitation is that the project cannot be comprehensive, but should focus on a few representative components keeping the system open for later enlargement. There are so many different activities in the framework of land and water management influencing the regime of large rivers that the analysis of all probable impacts is hardly possible. The selection of the most important factors to be analysed in the first phase of the project will be made by considering the local conditions of the case studies investigated. The modular structure of the decision support system provides an easy way to supplement the system by models suitable to predict also the impacts of other types of management actions. This enlargement can be executed during the application of the first results.

Considering all aspects listed here, the main task of the project is to construct a system of aggregated basin-wide models organized according to the various planned activities which can predict the trajectories in the change of the state variables in a large river basin describing the expected behaviour of the hydrological systems (Figure 3). The new vector of state variables determined by the basin-wide scenario analysis can be introduced later into the regional scenario analysis which is organized according to regions and is related always to the real problems of a particular area. Finally the two scenario analyses may be followed also by policy analysis.

There is also a theoretical problem which should be solved in the framework of the project: i.e. the interrelation between hydrological variables observed at different space-scales. This missing link still hinders, for example, the application of the results

achieved in representative and experimental basins for the characterization of large rivers. It is obvious that the hydrological variables observed at the closing section of a large basin represent in a physically integrated form all the impacts of hydrological processes occurring in a disturbed form over the catchment and having strong variability both in space and time. The smooth transition between the various hierarchical levels of both the data-base management and the model-systems requires the better understanding and the realistic simulation of the aggregation of processes.

3. The Structure of the Project

As is clearly indicated by the analysis of the scope of the project, the decision support system for managing large international rivers is composed of two closely interconnected subsystems:

- the data-base management, and
- the models for impact assessment.

Finally, as a third component of the project, the subsystems are interconnected with the development of softwares of the decision support system which are able to visualise the results in an easily understandable form and to produce an interactive dialogue between the system and the decision-maker, using personal computers.

Both subsystems are constructed like pyramids having large bases and when going upward in the direction of higher hierarchic levels, the data are more and more integrated providing at the top only some aggregated information for decision-makers sufficient to understand the present condition and the expected behaviour of terrestrial and aquatic ecosystems in the river basin investigated .

The basis of the data-base management subsystems is composed of the primary data collected in the basin (Figure 4). This set should include not only the hydrological data, but also information on geographical conditions, land-use pattern and water management activities. Representing the types of data along one of the horizontal axes of the basement of the pyramid, the following units might be distinguished:

1. Water quantity data:

- hydrometeorological data (precipitation, evapotranspiration, air and water temperature, wind velocity, humidity or vapour pressure, etc.);
- streamflow (discharge hydrographs at different sections of the river system);
- ice phenomena (date of occurrence of the various forms of ice in the river).

2. Water quality data:

- sediment transport (concentration or total sediment transport at the sections, specific soil losses in various subcatchments, etc.);
- transport of dissolved chemicals (concentration or total transport of various types of dissolved solids at the sections);
- oxygen balance (dissolved O₂, BOD, KOD, etc.);

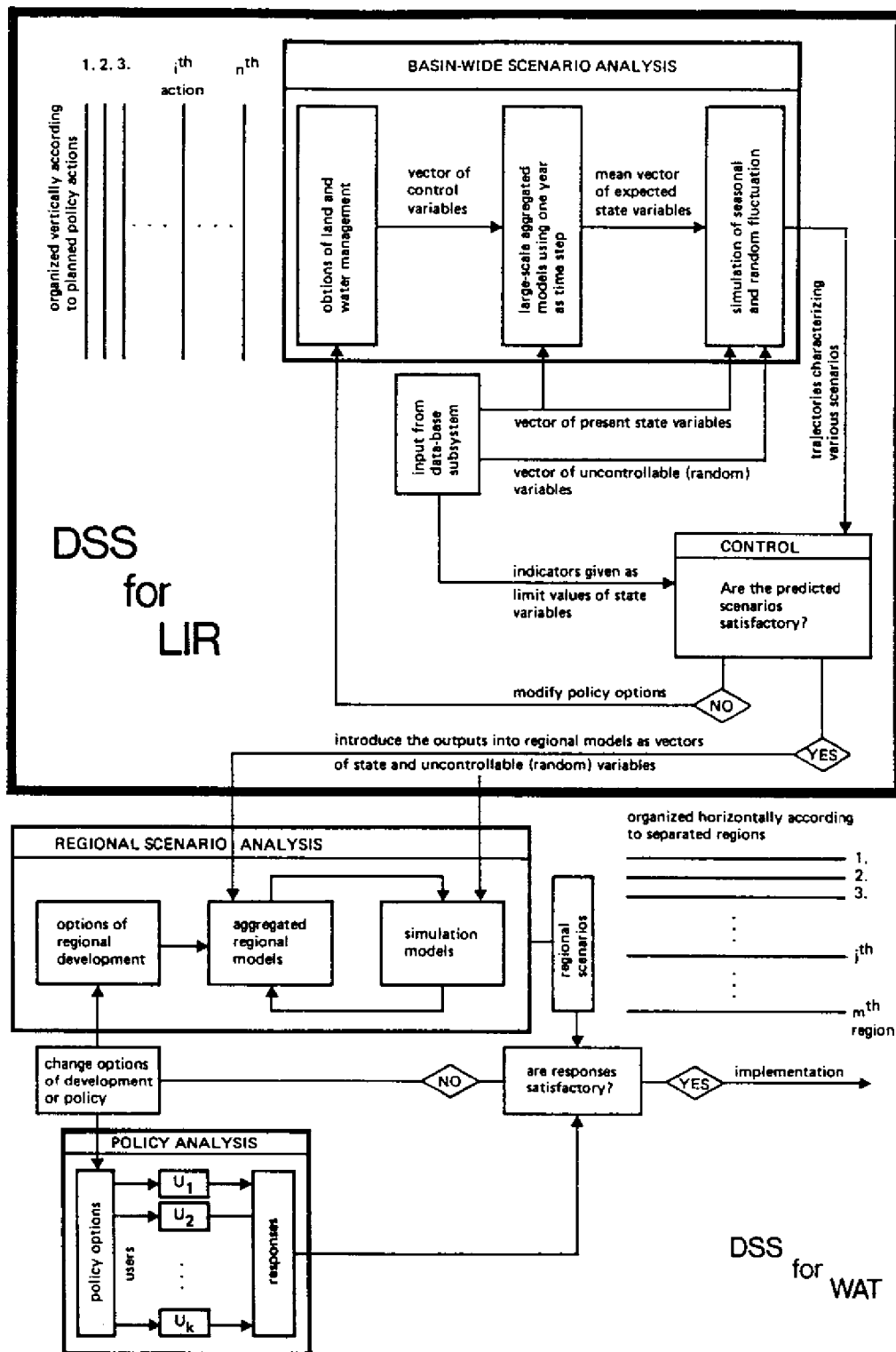


Figure 37.3

- aquatic ecosystems (parameters characterizing trophity, toxicity and saprobity of water, description of macrophytes, etc.).

3. Information on water management:

- water intakes from the natural to the social cycle;
- quantity and quality of effluents returned to the natural cycle;
- capacity and operation of reservoirs.

4. Data characterizing geographical conditions:

- altitude and climatic zone of the basin;
- slope conditions, channel length and other physiographic parameters;

5. Information on land-use

- rate of the different types of land use (forest, cultivated land distinguishing irrigated and rainfed agriculture, urbanized area, free-water surface, etc.);
- land-use management (type of cultivation, amount of fertilizers, yield, etc.).

Along the other axis of the horizontal base, the various approaches to data management can be listed. It is obvious that it would be unrealistic to attempt the construction of a generally applicable method for data processing and evaluation, because such a system does not exist. The local geographical and socio-economic conditions determine basically what types of data are required for the efficient management of land and water resources but at the same time the development of these conditions is also a function of the local hydrological regime. To mention one example: the development of paddy cultivation in South-East Asia was a consequence of the hydrological conditions being favourable for this type of land use, and now the existence of a society based on rice consumption requires a water management policy designed to improve the productivity of the land for this use. The socio-economic conditions influence also the efficiency of hydrological services and the availability of primary data in this way. It is evident, however, that the construction of data processing systems should consider also the character and the amount of data available in a region.

The other pyramid representing the subsystem of models used to predict factual (but not socio-economic) impacts is very similar to the previous one (Figure 5). On the vertical axis the hierarchical level of data aggregation is again represented. The horizontal base of this pyramid is composed of comprehensive models serving to simulate in detail the interrelationships between the conditions of the selected environmental elements and the probable variants of land and water management. The matrix according to which these models can be arranged in groups again has, as one of its axes, the various options of applicable methods, the use of which depend on local conditions and on the availability of data required for the solution of different models. Along the other axis of this matrix the various management activities can be listed, the factual impacts of which have to be investigated. As was already mentioned, in the present phase of research only the most important human interventions are selected among the numerous possible actions, these can be divided into three groups:

1. land use (deforestation, intensified rainfed agriculture, irrigation, urbanization, etc.)
2. runoff control (reservoirs, water transport, barrages, river training, flood control. etc.)
3. pollution (organic, inorganic, toxic, thermal originating from different sources).

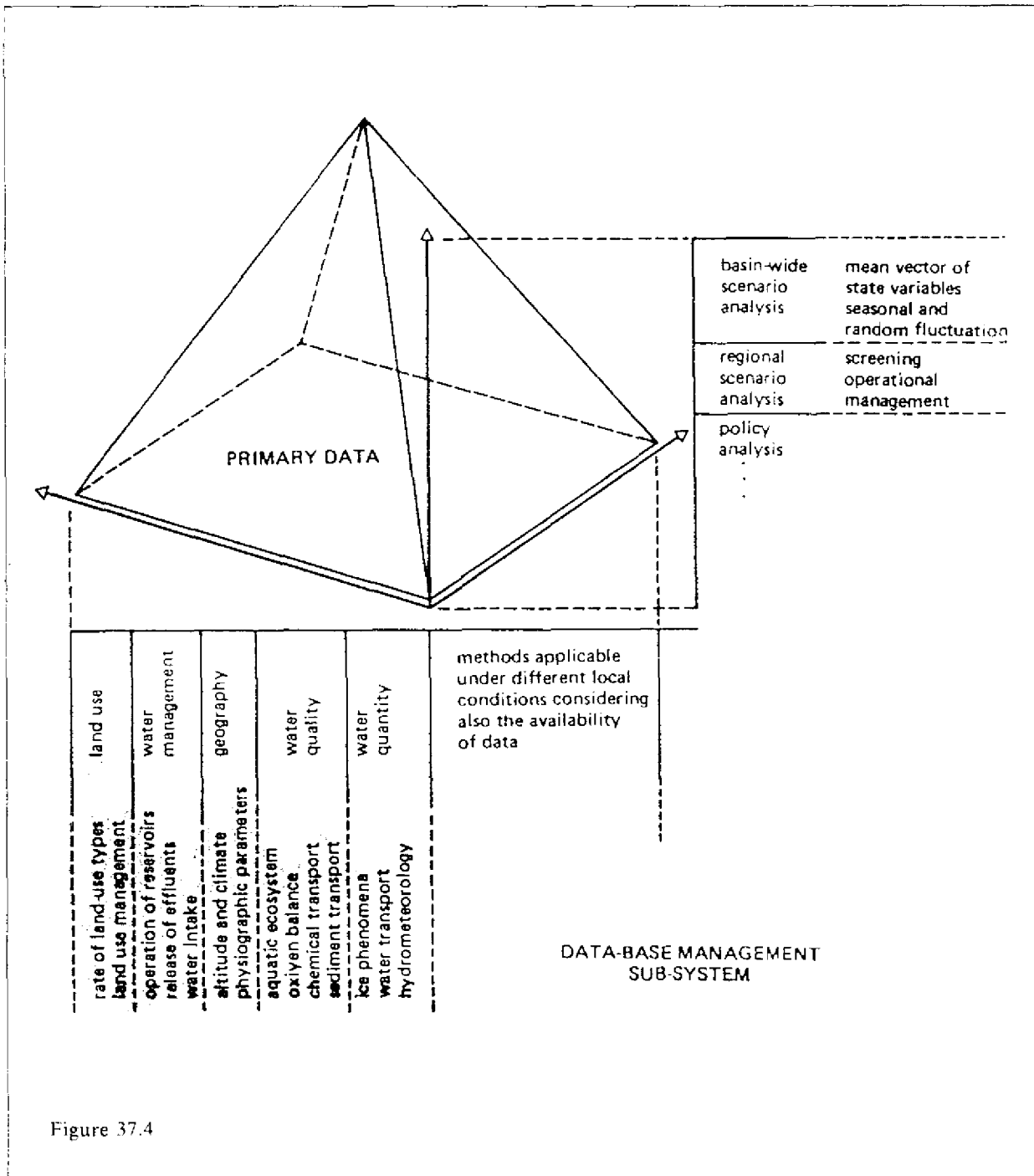


Figure 37.4

A considerable advantage of this structure is that the whole system can be divided into almost independent modules - and the modules further subdivided into interrelated compartments - and these units can be investigated separately. This provides the system with great flexibility, because several cooperating research institutes can start simultaneously to build up modules which are best suited to their experience and the lack of information delaying the preparation of one module does not hinder the development of the others. At the same time, strong central coordination is needed to ensure the compatibility of the modules and to consider the possible interactions among them.

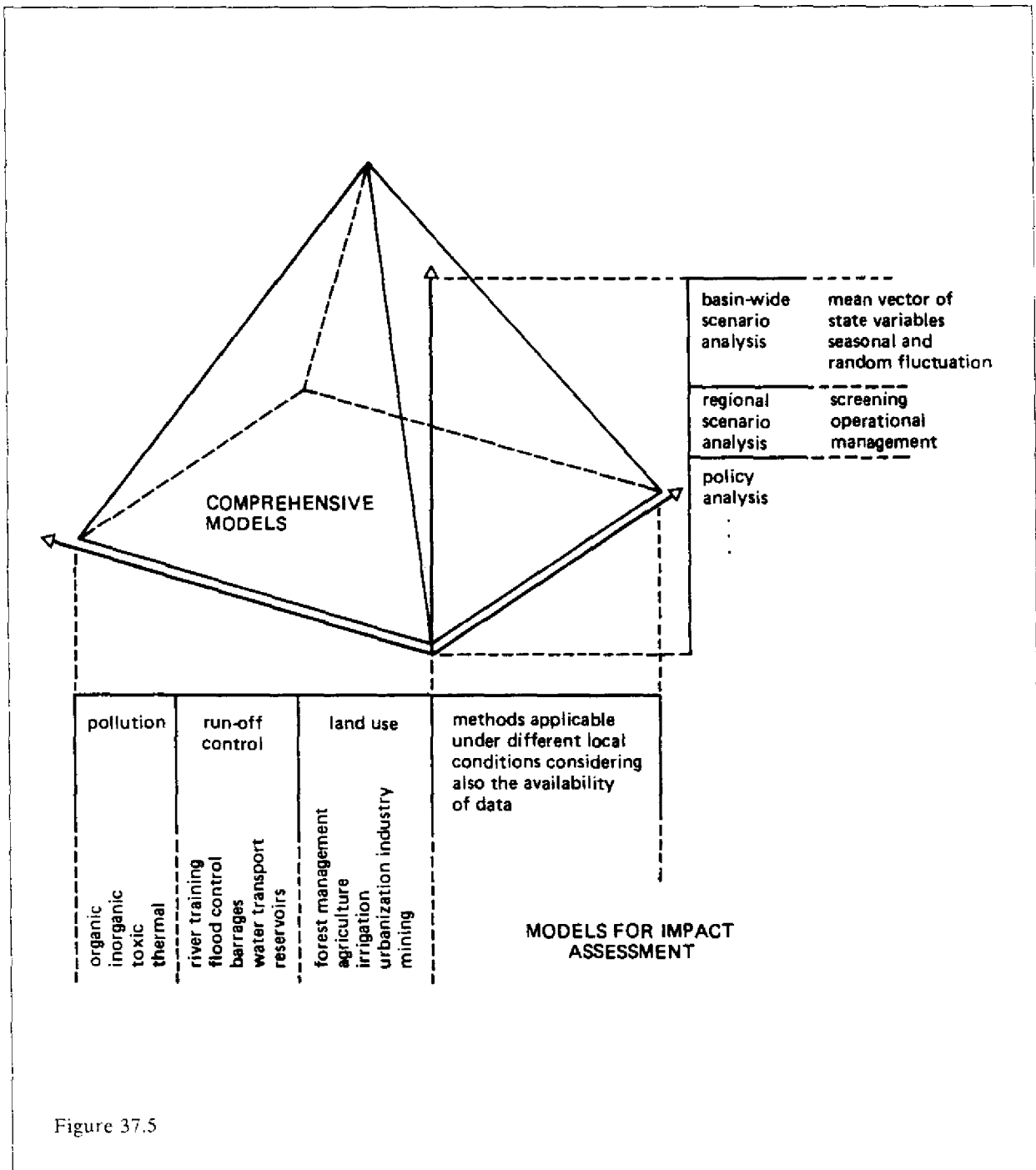
The system of models should remain as general as possible to ensure applicability under different geographical and socio-economic conditions. This basin-wide scenario analysis may also be divided into two levels, the first predicting the mean values of the state variables and the second their seasonal and random variation. It is also possible - depending on the character of the process investigated and on the structure of the model applied - to combine these two levels modelling the time-dependent processes directly and determining the average trajectories from the simulated time-series. It is obvious that parallel to the construction of the model-system, the data-base management should be also further developed to provide the system with the information required.

4. The Execution of the Project

The modular structure of the project makes it easy to distribute the actual research work between institutes which are willing to undertake the preparation of selected modules in one of the subsystems. At the same time, this type of work requires strong and continuous central coordination. This type of execution fits extremely well to the existing opportunities, because the limited funds available for the project are sufficient only to maintain a small coordinating group at IIASA, and because several research institutes have expressed their interest and willingness to take part in the execution of the project. To improve the central coordination, an Advisory Panel will be formed consisting of the representatives of collaborating institutes and prominent experts. The first task of the Panel will be to analyse and approve the detailed work plan which will serve as the basis for distributing responsibilities between the collaborating institutes and to harmonize their work both professionally and in time.

It is necessary to consider that several projects of this type have already been carried out, the results of which should be utilized. The components of HOMS of WMO-OHP (Hydrological Operational Multipurpose Subsystem of the WMO Operational Hydrological Programme) cover a large part of the primary data field of the basis of the data-base management subsystems. The World Climate Programme - Water (ICSO-WMO-Unesco) also has several components related to unified data processing and investigations dealing with scale problems. Similar efforts to standardize the collection and primary processing of water-quality data have been made by several WHO projects. Guidelines for the evaluation of water management and land use data were prepared by the Water Commission of ECE. The expected close cooperation with the relevant governmental organizations and with national institutions having performed similar research in the past may facilitate the concentration of our effort to find the best way to present hydrological information to decision-makers.

A large number of models have already been prepared and presented at the meetings of various water-orientated NGOs. Governmental organizations have collected, compared and evaluated these models, attempting to produce guidelines for environmental impact studies. The EMINWA programme of UNEP, the IHP of Unesco, the activities of the Un-DTCD



and the Mekong Secretariat can be mentioned first, but elements of models can be found also in projects executed by other UN agencies (FAO, WHO, IAEA, Commissions of ECOSOC), intergovernmental organizations (e.g. Rhine Commission), and national institutions. Here again the establishment of close cooperation is needed at first, and efforts should be concentrated on defining how the comprehensive models can be aggregated to suit the large space scale, the availability of data and the requirements of decision-makers.

There is another field also where cooperation with external organizations - governmental and national institutions - should be encouraged. It is strongly desired that the project does not remain on a theoretical level, and that its results be applied to as many cases as possible. It is hoped that both international organizations (UN agencies and international river commissions) and national institutions will join the project, making it possible to use the system under various conditions characterizing different large river basins. The applicability and flexibility of the system can be verified and improved in this way.

The analysis of two case studies was already foreseen in the original programme of the project. The first case study is the Danube basin. This choice is supported by the fact that IIASA is located in this basin, thus all the sources of information can be reached easily. Most of the riparian countries are members of the Institute. Since the cooperation network will be composed mostly of research institutes of member countries, a large number of specialists taking part in the project will already be familiar with the prevailing problems and conditions. The Danube basin is located in the temperate zone and the region is strongly industrialized. Most of the environmental and water management problems are caused by the increasing pollution of water. The expected environmental changes resulting from the construction of river barrages is also a burning issue for environmentalists in some countries. The extension of irrigated lands is not significant and the capacity of existing or planned reservoirs is not large either. When selecting the other case study, the main aspect is to find a basin the conditions of which supplement those prevailing in the Danube basin. Therefore an international river is to be selected, which is located in the arid tropical or subtropical zone, occupied by developing countries, where the main problems of land and water management are the control of flow by reservoirs and the utilization of water for irrigation. It is proposed, therefore, that the Senegal basin should be the second case study investigated by the project. Naturally any further case studies can be incorporated in the programme assuming that the interested international or national organizations are willing to sponsor the research.

Concerning the timing of the programme, a gradual execution is planned utilizing the modular structure of the project. It is foreseen that the main modules of both subsystems will be available in four years but some results will already be applicable within a period of one year.

PAPER 38

GAINS FROM INTERNATIONAL SEMINAR ON ENVIRONMENTAL IMPACT ASSESSMENT OF WATER RESOURCES PROJECTS, ROORKEE, DECEMBER 1985

A SUMMARY REPORT

Dr. Mahesh Varma

Synopsis

The Water Resources Development Training Centre at Roorkee, India, hosted the International Seminar on EIA of Water Resources Projects during December 1985. It was a well-attended event with nearly 200 participants from 15 countries and from several national and international agencies. Nearly 70 papers on 6 different themes were presented in seven technical sessions. Several recommendations of a far-reaching importance were generated. The outcome of the seminar is printed in three volumes of proceedings.

The present paper summarises the gains achieved from this significant international gathering. It gives the gist of technical discussions, the recommendations generated, and the objectives fulfilled during the seminar.

Introduction

The International Seminar on the EIA of Water Resources Projects was held on 12-14 December 1985 at the Water Resources Development Training Centre, Roorkee as a part of the tridecennial celebrations of the Centre. It was attended by nearly 200 delegates and guests, 40 of whom came from 14 different countries (Bangladesh, China, Egypt, Finland, Indonesia, Iran, Iraq, Jordan, Pakistan, Philippines, Sri Lanka, Thailand, U.S.A. and USSR) and 7 international institutions (AIT, ICID, IWRA, UNEP, Unesco, USAID and IBRD). Several national and international organizations co-sponsored the seminar.

The following themes were presented and discussed during seven technical sessions:

- Theme I : Water and Eco-systems (General)
- Theme II : Environmental Impacts of WR Projects - Surface Water
- Theme III : Environmental Impacts of WR Projects - Groundwater
- Theme IV : Environmental Impact Assessment - Procedures and Practices
- Theme V : Institutional Aspects of Environmental Impact Assessment
- Theme VI : Water Quality

Technical Content

In the discussion on Water and Eco-Systems it was generally agreed that EIA should be an integral part of project planning and feasibility studies, to ensure environmental integrity. Ecological disturbances created as a result of water resources projects, in respect of forests, greenland, agro-forestry, inundation, effect on wild-life habitat, fisheries, etc. should be balanced against economic gains as far as possible, and data on impacts of existing projects should be collected and analysed to frame guidelines for the future. With particular reference to India, the participants were of the opinion that overall environmental degradation in India, and ecological imbalance created by water resources projects should be assessed in detail and countermeasures worked out. The impact on irrigation water management received special attention and it was suggested that programmes for the improvement of network and on-farm water management be intensified so that the problem of seepage in conveyors and in field channels, and problems of waterlogging and salinity are better taken care of to achieve increased irrigation efficiency. It was also suggested that all state Governments in India should frame necessary pollution control laws, if this has not already been done. The need to restore the eco-system of the Ganga Valley was mentioned and the proposal for setting up a Himalayan Institute for Environment and Development received support.

Several papers were contributed on the theme of Environmental Impact of Water Resources Projects - Surface Water and the discussions were programmed in two technical sessions. The basic objective in water resources development was stated to be the combined optimization of water and land resources, so that available irrigation and water potential could be effectively utilized on a sustained basis. Socio-economic aspects are significant in developing countries, and safeguards and preventive measures should be incorporated at the project preparation stage. An integrated approach in the planning, formulation and execution of the projects should be adopted through simultaneous implementation of catchment area treatment, command area development, and construction of project works so that maximum returns can be obtained from the scarce inputs, whilst solving the all-too-familiar problems of waterlogging, salinity/alakalinity in command areas and premature siltation of reservoirs.

The authors and participants unanimously recognized the fact that development cannot be isolated from the environment. When complete mitigation of the impacts is not possible, they should be minimized. Scientific methods of evaluation and presentation through effective visual techniques should be developed and made use of. Conclusions based on theoretical research alone should be considered only if they are supported by actual field observations. Remote sensing holds a promise. Post-project evaluation would also be beneficial. Efforts are necessary for making significant improvement through sound environmental management policies. In order to arouse environmental awareness, planning programmes, workshops and seminars should be conducted frequently for the benefit of officials and the public involved in development activities having environmental impacts.

In the session on Environmental Impacts of Water Resources Projects - Groundwater, the need to control waterlogging, to make conjunctive use of surface and groundwater for irrigation, and to provide adequate drainage, formed the thrust of the discussions. It was emphasized that projects prepared for areas susceptible to waterlogging, such as those supplied from unlined canal systems, should provide measures for the prevention of waterlogging and soil salinity. Adequate monitoring of the water table in these areas should be ensured and in large canal irrigation systems, conjunctive use of surface and groundwater should be practised. Drainage of command areas by means of drains and pumping, wherever feasible, should be included while preparing new project plans.

In the discussions on EIA - Procedures and Practices, the experts expressed the view that the concept of environmental development should be considered in the long-term, whereas economic valuation is a short-term approach. Technology need not necessarily be adverse to the environment since in developing countries the biggest threats to the environment are poverty, illiteracy and the population explosion, and their consequences such as deforestation, soil erosion and water pollution. The adverse effects of technology can be mitigated by introducing suitable safeguards at the planning stage but technology is essential for development. Water resources development produces geophysical and social changes which are subtle and complex. Detailed and thoughtful planning of projects is therefore essential.

A systematic approach to planning is also essential. Modelling, optimization and computer techniques can be used with advantage. Resolving conflicts by planning is an area which requires basic research. The need to intensify continuing education programmes for planners and decision-makers was emphasized. It was also clearly indicated in the discussions that research should be an integral part of engineering action, and an action research approach should be followed. Institutionally, there is a need to bring universities and design-construction-management agencies together, to complement the actions of each by thought and continuous feedback. It was also considered imperative that emphasis be given to the development of self-reliance. This is to be distinguished from isolation and introversion. Whilst it is essential to be conscious of developments elsewhere, indigenous self-sustained capability must necessarily be developed.

While discussing the Institutional Aspects of EIA it was emphasized that environmental impacts of water resources projects must be given the same in-depth evaluation as the technical and economic aspects. Especially in developing countries where this awareness has only recently arisen, it is necessary to establish a suitable institutional framework for EIA so that legislation is enacted and agencies with effective responsibility for EIA are identified and/or created. Where environmental laws and institutions have been created, the implementation is found to be lacking and agencies are handicapped for want of funds and staff. Suitable Environmental Units need to be established at the State and provincial level as well as at the Central or Federal level with effective linkage and communication with various agencies responsible for water policy formulation and implementation. Institutional aspects of EIA are multidisciplinary (political, legal, social, economic and technical) and it is necessary to impart multidisciplinary training to those involved in the planning and management of water resources projects.

The main theme of the during discussions on Water Quality was that quality aspects and assimilative capacity of water bodies should be given due importance in EIA studies of water resources projects.

Recommendations

The following recommendations were adopted at the concluding session of the seminar:

1. It is imperative that an awareness should be developed for the need for not only EIA but a sound management system to suit all geographical and geophysical conditions such as mountainous, flat and coastal areas, arid and semi-arid areas, etc.

The participants were conscious of the damage caused to the environment resulting from inadequate appreciation of EIA in planning, implementation and operation of water resources projects, but felt that this awareness must be inculcated and developed in all

human beings specially among decision-makers through formal and informal education programmes.

2. To further the objective of developing this awareness among professionals and senior students, copies of the proceedings of the seminar should be supplied free of cost to libraries of institutions involved or concerned with environmental protection in water resources development and water resources management.

3. The information and knowledge contained in the proceedings of the seminar should be synthesized for use as a guide and teaching aid. The synthesis should be in two major parts, one general, dealing with water resources development long-term objectives, and the other concrete, with short-term and immediate objectives for implementation.

The preparation of the syntheses should be entrusted to a few selected specialists and should be reviewed by other authorities before being printed.

4. Training and information programmes, specially tailored to meet the needs of specific countries or regions should be organized at suitable institutions. These programmes should begin in 1986-87 and should be expanded to cover all countries. The results of such programmes should be assessed periodically.

The teaching methodology, course contents, programme duration, etc. should be reviewed occasionally by a working group.

5. Case studies should be conducted and institutions identified to act as focal points for the dissemination of these studies for the benefit of user organizations and institutions.

6. The seminar identified environmental impacts in terms of resettlement, erosion, deforestation, waterlogging, salinity, coastal erosion, water quality, esthetics and others and agreed that an interdisciplinary treatment of the problem be attempted and conflicts between ecological and socio-economic effects be resolved as best as possible.

7. An action plan to mitigate the impacts on the environment is a logical step forward following an EIA. Remedial measures should be designed and implemented and the information and technology generated should be disseminated for future planning and management.

8. Planning for water resources development should be sustainable, integrated and comprehensive, taking into account all components such as watershed, regime, downstream flood flows etc. and all technical, scientific and socio-economic effects, both long and short-term. The effects likely to accrue from inadequate implementation should be identified in the project report.

9. Continuous monitoring of the environmental effects of projects and their dynamic management keeping in view all interdisciplinary aspects should be mandatory for all water-resources projects. Improved technology, such as remote sensing should be made use of for monitoring and management.

10. A data base for the EIA should be started and arrangements made for exchange of information among user agencies and institutions. Every major water resource project should have a concomittant data base.

11. Public involvement in decision-making concerning Water Resources Projects should be encouraged. Open public debates should be arranged, if necessary and possible alternatives should be presented during the debates.

12. UNEP, Unesco and other agencies should be requested to implement the above recommendations and to support international and regional institutions such as the Water Resources Development Training Centre, Roorkee involved in training and research in water resources planning and management, to develop teaching of environmentally-sound management techniques suited to specific regions or countries.

13. Working groups at national level should be constituted to take action for implementation of the recommendations of the seminar.

14. Organizers of the seminar are to initiate a follow up of the above recommendations.

Case Studies and Exchange of International Experience

Thirty case studies dealing with a variety of environmental issues were presented at the Seminar. These included studies from 7 different countries (Brazil, Canada, India, Korea, Pakistan, Philippines and USA), on over 25 specific projects as well as five country studies. In India such studies related to the states of Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tamil Nadu and Uttar Pradesh. All this provided a unique opportunity for exchange of information and experience from different parts of India, and from different countries of the world.

The various environmental impacts that were mentioned included destruction of cultivated land, grazing land and forest land; land submergence; agro-forestry; wild life; waterlogging, soil salinity, soil erosion; sea water intrusion; water quality; rehabilitation; socio-economic disparities; employment; land-use and zoning; hydrology; recreation and health. In one study the ill-effects of a sectorial approach were highlighted. Use of mathematical models, computer analysis and remote sensing also figured in the studies. The Seminar served as a unique forum for bringing together people with varied ideas and experiences for a better understanding of each others' theses.

PAPER 39

LARGE AND SMALL DAMS

R. Vidyasagar Rao⁴⁰

1. Introduction

From the dawn of civilization India has primarily been an agricultural country. Agriculture still continues to be the main occupation of the country sustaining about 70 percent of its population. Vast areas are now under cultivation, double and triple cropping being practised in many regions.

India, like most other countries, has uneven rainfall. The annual average rainfall is 1 170 mm, but there are considerable variations in both space and time. For example, Cherapunji in the north-east receives an annual average rainfall of 10 600 mm which is perhaps the highest in the world, whilst in the Rajasthan desert in the north-west the annual rainfall is only 126 mm. The seasonal and annual variations in rainfall make the Indian economy and planning highly dependent on the monsoons. The dependence on rainfall renders cultivation precarious and serious droughts have brought untold miseries to the people in the past. This underlines the need to harness the rivers of India for irrigation.

India is a vast country with a wide diversity of topography, climate and vegetation. Its area is 328 Mha, of which 186 Mha or 56.7 percent can be irrigated. India has a very large population to support which is expected to attain 986 millions by 2000 (the 1986 level being 761 millions) and the demand for foodgrains will increase from 150 million tons in 1985 to 240 million tons by 2000. This large increase of about 60 percent in foodgrains demand can only be met by the creation of new irrigation schemes.

The construction of dams for the storage of water in India is as old as recorded history. From 1860 to 1947, about 190 dams, large and small, were constructed with a total gross storage capacity of about 13 650 Mm³. Small dams, particularly tanks, have played a vital role in the history of Indian agriculture. One notable irrigation structure, the 'Grand Anicut' built in the 2nd century in southern India in the Cauvery River Delta, has stood the test of time. Since Independence, a number of large and medium dams have been constructed in the country and this has contributed substantially to the rapid pace of development of irrigation potential. This in turn has played a significant role in the country's attainment of self-sufficiency in foodgrains. Hirakud, Bhakra and Nagarjunasagar are a few examples of major dams completed after Independence. By the end of the Sixth Five-Year Plan, a total irrigation potential of 69 Mha has been created of which 30.82 Mh are major and medium projects. Of the ultimate potential of 113.5 Mha the contribution of major and medium projects is expected to be 58.5 Mha. Thus it can be seen that the minor

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irrigation projects contribute about 55 percent of the irrigation potential created so far and its contribution to the ultimate potential is expected to be around 50 percent.

2. Major, Medium and Minor Irrigation Schemes

In India, the classification of schemes is not based on the size of the dams. The irrigation projects are divided into three categories: major, medium and minor. Until recently, this categorization was based on the cost of the project. At the present, projects of more than 10 000 ha are considered to be major projects. Medium projects range between 10 000 and 2 000 ha and projects below 2 000 ha are considered to be minor. By and large the major and medium schemes comprise storage and diversion weirs across rivers and streams while minor schemes consists mainly of small storage works and development of groundwater resources by tube wells and dug wells. In this paper, major and medium irrigation schemes will be combined under the title of large dams and minor irrigation schemes will be referred to as small dams.

3. The Large Versus Small Dam Controversy

For some time now, there has been some controversy in India and elsewhere on the adverse effects of large dams. Environmentalists and water resources development planners have often opposed one another, the former vehemently opposing construction of large dams and the latter favouring them. The criticism of the environmentalists is mainly centred around the adverse impacts of large dams. They assert that nature is very fragile and developmental activities which change the existing natural balance are not advisable, and therefore advocate that irrigation development should now concentrate on small dams and groundwater utilization which have comparatively fewer adverse effects.

Before the relative merits and demerits of large and small dams are discussed, it may be of interest to consider whether one type of dam could replace the other totally. Conceding for the sake of argument that the minor irrigation schemes are better than the major and medium schemes in all respects, the question would then be whether the balance of irrigation potential of 44.5 Mha could be created with minor irrigation schemes alone. If this is not possible, then the problem will be to decide how much area should be covered by minor irrigation schemes and how much by the major and medium ones. Another important aspect that should be considered is that large dams cannot always be built where desired, whereas small dams can be constructed at most locations. A large dam needs favourable geological, hydrological, topographical conditions and an adequate command area. Therefore, it might be necessary to consider the construction of large dams wherever such favourable conditions exist, even though these dams may have certain adverse impacts as long as these are acceptable. No development project can exist without having some adverse effects. What should be aimed at is either to ameliorate or minimize the adverse impacts that occur in the wake of development projects. However, in those cases where the adverse impacts outweigh the development objectives then there may not be any choice other than abandoning such projects, as happened in cases such as the Silent Valley project in Kerala.

The various adverse effects associated with the construction of large size water resources development projects as argued by the environmentalists are:

1. Large dams necessitate massive population displacements because of reservoir submergence, leading to social and economic distress for the displaced population.

2. Large dams submerge valuable forest land, cultivable land, plantations, valuable flora and may in some cases lead to the extinction of rare species of fauna.
3. Because of the assured supply of water from large dams in two or even three seasons of the year, farmers tend to over-irrigate which leads to waterlogging and increased salinity of soils, thus progressively diminishing the productivity of land.
4. Dams increase the incidence of water-borne diseases such as malaria and schistosomiasis because of the increase of mosquito and snail populations.
5. Trapping of silt by large dams affects the regime of the river downstream. Reduction of flows downstream, especially in the dry season, may increase the salinity level of the river water beyond tolerable limits for downstream users.
6. Seismic activity in and around the reservoir area increases because of the mass of impounded water. Major landslides in the periphery of the reservoir can endanger the dam and the people downstream.
7. Reduced flow affects migratory fish, causing a decrease in the desirable fish population.
8. The damage caused to life and property by failure of a large dam can be disastrous. Flood control measures including flood embankments have not reduced the incidence of floods or flood damage significantly.

In order to make an objective assessment of the issue, it would be appropriate to consider the benefits that can accrue from large dams but not from small dams.

4. Benefits from Large Dams

4.1 Reliability of supplies

The large dams provide assured water supplies for irrigation, municipal and industrial requirements. If the dams are designed to have a carry-over capacity, they cater for the needs of the crops in the following years if rainfall becomes erratic.

4.2 Hydropower

Large dams offer generation of substantial firm power because of the large heads and storage facilities. Though hydropower is conventionally considered as peak power, hydropower can supply base load where thermal power is absent, as in the case of Kerala and Karnataka States. Hydropower is cheap and uses a renewable resource - water. The cost of generation of 1 kW of energy is about Rs. 0.35 for a large storage dam, while for thermal stations it is Rs. 0.5 and upwards, and for stations using diesel fuel, the cost may be as high as Rs. 1.50. The capital cost of construction of large hydropower systems is about Rs. 10 000 per kW while it is Rs. 12 000 per kW for thermal stations. Further, use of coal as a fuel for power production involves atmospheric pollution and waste disposal. Nuclear waste disposal has been a serious issue in many countries, where there has been large-scale development of nuclear power. Small dams cannot provide the required amount of firm power because small storage cannot effectively regulate the erratic nature of river flows for sustained power generation. Besides, the cost of 1 kW of installed capacity may be multiplied by 3 for a small dam.

4.3 Flood Control

Large dams offer substantial flood protection to downstream areas by temporarily holding back the flood flows and moderating the peak value. The regulation offered by large dams by the storage and operation of gates is absent in small dams. It is not true to say flood control and embankments schemes have not afforded flood protection and reduced flood damage. The problem, wherever present, should be studied in its entirety: river morphology, changes in river course, encroachment on flood plains and developmental activities in areas protected, change in rainfall pattern in the area, etc. Before construction of Ukai dam in South Gujarat floods were very common. During the 94 years up to 1970 floods at Surat city had risen 19 times above the danger level of 28.96 m, the maximum level being 31.55 m in August 1968. Due to Ukai dam the situation has altogether changed. Surat and areas downstream are now free from floods. As against 42 480 m³s⁻¹ in 1968, the maximum flood peak released since completion of dam has been only 13 620 m³s⁻¹. It is now realized that with some flow forecasting techniques the efficiency of large dams for flood protection can be increased enormously. Integrated operation also increases the performance of the system for flood control purposes.

4.4 Water Management

Large irrigation systems with a network of canals are more amenable to the introduction of a rotational supply of water and better water management policies. Modern communication networks using VHF can be introduced to monitor releases in main canals depending on the rainfall in the command area. Water can be stored between cross regulators when not required. High irrigation intensities of the order to 160 percent are achievable in large command areas. With improvement in water management and adequate drainage provisions, it is possible to counteract the adverse impacts of waterlogging and salinity. Conjunctive use will keep groundwater levels in check. Vector control and spread of infectious diseases are also manageable.

From the point of view of command area development activities, large command areas subject to a unified irrigation system are preferable. It is easier for agricultural extension workers to operate in large schemes, as farmers can see results and learn from neighbouring farms or demonstration farms. Similarly the supply of pesticides, herbicides and seeds can be better regulated. Land consolidation and rectangularization of holdings may also be possible. Marketing and communication can be better planned. All this cannot be expected if irrigated areas are spread over a number of pockets instead of one consolidated unit. The concept of a unified agency for command area development like CADA fits large units of irrigated area rather than small ones.

4.5 Water Quality

The quality of water in many of our river systems has deteriorated considerably due to increased urbanization and industrialization. The non-monsoon season flow in many rivers is too meagre to evacuate this pollution load. It is paradoxical that large volumes of water are lost to the sea in the monsoon which could otherwise be put into effective use by means of storage and released to the rivers in the non-monsoon period. Large dams can be designed for specific releases from water quality considerations. The power releases at Hirakud dam have augmented the non-monsoon flows in the Mahanadi with the result that no cases of pollution have been reported.

4.6 Recreation

Recreation in and around many large reservoirs have made the environment more pleasant, and have provided new facilities for the people. Examples are Brindavan Gardens (Krishnarajasagar Dam in Karnataka), Malampuzha Gardens (Malampuzha in Kerala), Sant Gyaneshwar Udyan (Jayakwadi in Maharashtra) amongst others. Reservoir areas provide economic activities as well as recreational facilities for water-skiing, swimming, boating and fishing, etc. The scope for developing recreation centres on large reservoirs appears to be greater than on small reservoirs.

5. Disputable Aspects of Adverse Impacts of Large and Small Dams

There are certain adverse impacts which have been attributed mostly or even exclusively to large dams but which are not generally considered in the case of small dams. These issues may to some extent be disputable, depending on specific situations as will be discussed in the following section.

5.1 Submergence aspects

There is a belief held by many that the area of submergence due to a large reservoir is much greater than would be the case for a number of small reservoirs created for the same storage. Unfortunately not much data is available on the submergence and cost aspects related to small dams. However, an exercise was undertaken to compare the cost and submergence aspects of large dams with that of small dams by considering the case of the Jonk sub-basin in Mahanadi. In the study, two alternatives were considered. The first alternative was Girina dam, the major project with a storage of 603 Mm³ and the second alternative consisted of a substantial reduction of the storage at Girina dam compensated by other small storage dams. It was seen that Girina could be reduced to 185 Mm³ of storage, the balance of 418 Mm³ being provided by 8 small storage dams. However, even a rough estimate of storage cost only showed that the cost of the second alternative was 150 percent higher than the first and also involved 60 percent more submergence (Table 1).

Another example that could be cited in this context is the Heran Dam in Gujarat. The construction of the Heran Dam could not be undertaken because of agitation by the local population. A preliminary evaluation made by the Government of Gujarat to reduce the height of the dam and construct another small dam upstream has shown that the population affected and the area of land submerged could be reduced only marginally. But the tribal habitats and forest land increased tremendously. Information on submergence areas vis-a-vis irrigated areas of small irrigation projects are not readily available. But based on information available for major and medium projects, it can be seen that the submerged area represents 3 to 10 percent of the irrigated area in the case of major projects, whereas for the medium projects this ratio ranged from 10 to 25 percent as shown in Table 2. On the basis of the same analogy, it can be deduced that in the case of small projects the submerged area is likely to represent 50 to 60 percent of the irrigated area (Table 2).

5.2 Cost aspects

To replace a single large dam irrigating 100 000 ha, 50 small dams each irrigating 2 000 ha would be needed in the upper or lower reaches of a watershed. Such a large number of alternative sites is rarely available in practice, necessitating a curtailment in the envisaged development. Construction of dams in the upper reaches involves problems of transporting skilled labour, machinery, etc. Further, the submergence also may involve rich forest land.

Construction of dams in the lower reaches involves more submergence of usually cultivated land per unit of storage due to the flat nature of the topography.

Advocates of small dams stress that the cost per hectare of tank projects is much less than for large irrigation projects. This is true because large dams involve mechanized construction, transport of cement and stone over long distances, construction of communication lines, housing colonies, cost of spillway, design cost, and so on. In small dams, local unskilled labour is used with local material to construct the embankment. Further, for a small project the distribution system is less expensive as the canals are mostly unlined and are constructed with the help of the farmers. The input of labour by the farmers is not generally taken into account when computing the cost. Maintenance costs for small dams are not usually taken into consideration. In an economic analysis the cost per hectare is not high but the net present worth of long-term benefits, the cost-benefit ratio and the internal rate of return should be considered.

5.3 Evaporation

The annual evaporation in India is 1.5 to 2 m. Large volumes of water are lost by evaporation in small reservoirs because of their shallow depths as compared to those of large reservoirs.

5.4 Groundwater use

Groundwater development forms the bulk of the minor irrigation programme and can be a people's programme implemented through individual and non-cooperative efforts with finances obtained from institutional and other sources. It is widely believed that groundwater can provide the farmer with an instant supply of irrigation water and its use can control waterlogging and salinity. Though groundwater could perhaps supplement and augment surface water supply it cannot altogether replace large irrigation systems.

The use of groundwater is dependent on availability of cheap power whether electric or diesel. Groundwater use could involve a lot of mechanical hardware like screens, electric motors and pumps which need proper maintenance and the reliability of the power supply to agricultural sectors has not been satisfactory in most of the Indian States. The statistics show that the tube wells in Uttar Pradesh functioned for only 17.8 percent of the time on account of mechanical defects and non-availability of power during the period 1974 to 1980. In many areas groundwater has been reported to be saline and its continued use has caused soil salinity. In coastal areas, groundwater pumping caused sea-water intrusion to the aquifer, rendering the groundwater supply unfit for any type of use. This has happened in Madras city and the coastal areas in Sourashtra. Groundwater flow is closely related to low flows in most river systems in the dry season. Any large-scale groundwater development will adversely affect the low flows which are already much less than what is required in most river systems from water quality considerations. Irrigation could prove to be a boon to groundwater development, as the recharge from irrigated areas will increase the groundwater levels.

5.5 Seismic Aspects

Reservoir-induced seismicity is another debatable point in view of the present level of data and knowledge of the deep structural formations which preclude definite conclusions. A study of 425 large dams in the world has shown that only in 15 cases were the seismic forces observed to have gone up after construction of the reservoir. In 10 out of these 15

cases the magnitude of earthquakes was less than 5 on the Richter scale. Seismological observations at Bhakra, Pong and Ramganga Dams have not recorded any increase in seismicity due to impounding of water in these large reservoirs.

6. Adverse Impacts Associated with Large Dams and Mitigating Measures

6.1 Population displacement

The most important and emotive environmental issue in India at present is the submergence of land and consequential population displacement. It is here that the water resources engineers are faced with big dilemma. If the submerged land is inhabited, population displacement and submergence of agricultural land and dwellings become major issues. If the area is sparsely populated, then it is either forest land or some valuable flora that may be submerged. Though displacement of populations occurs in all developmental projects, in water resources projects the effect of submergence is more pronounced because of the extent of submergence at one place.

As regards displacement of population, the main issue is not the displacement itself but the implementation of the proper rehabilitation measures and timely payment of adequate compensation. The Maharashtra Government in its recent Resettlement Act 1976 has provided for many amenities including reservations of up to 15 percent of the command area for resettlement purposes. Almost all state governments in India are aware of this problem and are taking suitable measures for the protection of rights of the displaced persons. A package of rehabilitation measures has been drawn up for the Narmadasagar and Sardarsarovar Dams, planned on the Narmada, in view of the magnitude of the population affected. Some of the projects which involve large-scale population displacement such as the Tikkerpara Dam on the Mahanadi and the Bhopalaptnam Dam on the Indrawati have been deferred on this account.

It cannot be stated that small dams do not displace populations. However, the impact of each small dam is not felt in the same way as in the case of a large dam. A railway line or national highway running into thousands of miles also would displace lots of people but its impact is not as forceful as that of projects such as reservoir or mining where the people are concentrated in one location. This is the case of a number of small dams compared to large dams.

It is argued that the large dams cause submergence of forest lands. It has been worked out that the water resources projects are responsible for 12 percent of total reduction of forest cover. If the compensatory afforestation of recent projects is also considered then this percentage is less. The Forest Act of 1980 and the clearance procedures set out by the Department of Environment safeguard reasonable interests in this respect.

6.2 Waterlogging and soil salinity

Waterlogging and soil salinity are problems which arise in many irrigated areas. Steps are being taken to mitigate the problem. Some of these are:

- (a) scientific assessment of water requirement of crops on the basis of agrometeorology;
- (b) introduction of rotational water supply to farms;

- (c) provision or re-excavation of main and intermediate drains as part of project construction activities;
- (d) provision of farm drains as a component of on-farm development works;
- (e) conjunctive use of groundwater and surface water to lower the water table.

Water and Land Management Institutes have been set up in several states to train officers of the agriculture and irrigation departments in water management. These institutes impart training on remedial measures for waterlogging and soil salinity problems.

6.3 Aquaculture

Environmentalists argue that the yield of river fish has been reduced because of dam construction. There is no doubt that any barrier across the river, particularly dams, affect the upstream migration of species like salmon etc. unless special provisions are made at the dams. In India, such provisions are made where required. Migratory species are almost non-existent in the Indian river system except in a few snow fed Himalayan rivers. Due to the reduction of low flows downstream of a dam, a certain reduction in the yield is likely to occur. However, this is adequately compensated for by rearing fish in the reservoirs created by dams where a copious water supply is always available. In the Ukai Reservoir, fishery has been successfully developed.

6.4 Effects on downstream areas

There exist certain misconceptions as regards the effects of dams on riparian users of river water. The position in reality is generally favourable. The regulated releases from dams firm up water supply for irrigation and municipal uses. The storage size of a dam is invariably designed to cater for existing users. The Nagarjunasagar Dam in Andhra Pradesh has provision for releasing the mandatory flows to take care of the riparian rights of farmers of the Krishna delta.

6.5 Dam failures

Dam failures are no doubt disastrous. In India there has been no large dam failure in recent times. With more rigorous flood estimation, better foundation investigations and their treatment, quality control during construction, the risk of dam failures can be minimized to a large extent. Small dams, because of non-exacting standards for the estimation of the design flood, are more prone to failure as is evident from recurring tank breaches in Karnataka and Sourashtra. The breach or failure of small dams may not result in loss of life but they cause damage to dwellings and crops as well as loss of animals.

6.6 Other issues

Large dams trap silt thus depriving the lower reaches. This may affect areas where inundation irrigation is practised, due to loss of nutrients. Most parts of the country practised only rainfed agriculture and the provision of irrigation has improved yields and thereby economic conditions dramatically as in the case of the Rajasthan Canal Project, Ukai, Kakrapar, Nagarjunasagar, etc. There are no reports showing that any area has suffered due to the supply of silt-free water. Trapped silt no doubt reduces the life of reservoirs, but no developmental activity has an infinite life and all need replacement. A dam is designed to have a reserve below the dead storage level for trapping the silt. By

proper planning of silt storage and catchment management, the life of the reservoir can be preserved or extended.

Large dams do require huge capital investments. The returns do not start flowing even after the completion of the dams because the distribution system may not be ready. Even where the returns start to flow they are only partial. This problem is not encountered in the case of small dams where the returns start flowing as soon as the scheme is put into operation.

7. Conclusion

The attainment of the ultimate irrigation potential of 113.5 Mha in India will involve massive irrigation development. Groundwater and minor irrigation are supplemental in nature and cannot form the main thrust of the national irrigation strategy. It is not correct to view minor irrigation schemes as an alternative to the major and medium ones. Much of the criticism of large dams has emanated from environmentalists in the developed countries where most of the possible developmental activities in water resources have already taken place and where there is hardly any need for additional food due to limited population growth. Self-sufficiency in food has been the thrust of the planning process in all developing countries and the tempo of this thrust should not be diverted from the goal by overemphasizing the adverse environmental impacts without weighing them against the enormous benefits and potentials.

Modern-day project planning is more exacting and comprehensive and all aspects of impacts on the environment are considered in detail at the planning and implementation stages. Most of the adverse impacts of large-scale water resources development can be minimized, compensated or even eliminated. The large and small schemes have their role to play in furthering the development of water resources. Therefore, the controversy regarding large dams versus small dams is not rational and in reality the large and small dams should coexist without any conflict.

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Table 1 - CASE STUDY FOR JONK SUB-BASIN

Project	Catch area (km ²)	Type of the project	Status of the project	Location		Gross Storage (Mm ³)	Cost (MRs.)	Submergence (ha)
				Lat (N)	Long (E)			
Alternative A								
Girana	1 777	Major	Proposed	20°10'	82°37'30"	602.7	91	7 260
Alternative B								
1) Karmel	282	Major	Proposed	21°21'	82°38'	150	52	2 375
2) Upper Jonk	342	Medium	Ongoing	20°44'	82°26'30"	80.5	46	1 400
3) Kauria	401	Medium	Proposed	21°15'	82°33'55"	68	26	1 830
4) Bhurkuni	202	Medium	Proposed	21°07'	82°33'	50	11	945
5) Balar	81.5	Medium	Ongoing	21°31'57"	82°29'35"	39.6	14	547
6) Deogaon	39	Minor	Proposed	21°20'	82°26'30"	15	15	500
7) Kurkuti	86	Minor	Proposed	21°19'30"	82°32'	9.7	94	315
8) Rangora	189	Minor	Proposed	21°19'	82°35'	5.5	86	248
9) Girana	1 777	Major	Proposed	20°10'	82°37'30"	185	45	5 400
Total (Alternative B)					603.3		227	11 560

Table 2 - Statement showing Details of CCA and Submergence area underexisting and Proposed Major Medium Water Resources Projects

State	Name of Project	Command Area (ha)	Submergence Area (ha)	Ratio of Submergence to Command area (percent)
Major Project				
Andhra Pradesh	Nagarjuna Sagar	867 000	28 500	3.29
Bihar	Chandan	45 000	1 080	2.40
Gujarat	Kadana	22263 157	16 600	6.31
Gujarat	Sardar Sarovar	1 290 000	37 030	2.87
Karnataka	Tungabhadra	528 981	37 800	7.15
Karnataka	Bannithora	20 230	2 132	10.54
Karnataka	Malaprabha	218 910	12 900	5.90
Kerala	Kuttiadi	25 495	1 100	4.31
Mydhya Pradesh	Tawa	28 421	20 200	7.11
Maharashtra	Mula	97 900	5 358	5.47
Tamil Nadu	Mettur	201 209	15 346	7.63
Medium Project				
Karnataka	Taraka Reservoir	8 920 1 100	12.33	
Maharashtra	Katepura	8 325	1 200	14.41
Maharashtra	Kanhar dam	9 182	2 014	21.93
Tamil Nadu	Vaigai Dam	9 234	2 419	26.10

PAPER 40

METHODOLOGICAL GUIDELINES FOR INTEGRATED ENVIRONMENTAL EVALUATION OF WATER RESOURCES DEVELOPMENT

L. Hartmann

Introduction

Recent experience in water resources development as well as in other engineering fields point to an increasing number of conflictual situations. In many cases the development, planned to improve the situation of people, turned out to be a failure and in some cases even a catastrophe; in others the expected economic gains did not materialize. In yet other situations the so-called improvement led to unexpected chain-reactions or side reactions accompanied indirectly by heavy damage to both the economic situation and to the environment.

It was therefore decided to deal with this phenomena within Unesco's International Hydrological Programme. A list of hydro-environmental indicators and indices was selected by a first expert group (A.3.2.) In its final report the work group concluded that:

- (a) the evaluation of a water project must not be limited to hydroecological factors alone. The project must be viewed as part of an environmental system encompassing physical, biological, chemical, economic, social and cultural components.
- (b) New water projects are now generally being examined as thoroughly as existing scientific expertise will permit but certain basic inadequacies remain.
- (c) The results of water project assessments cannot be readily interpreted by personnel untrained in the relevant disciplines.

Furthermore it was stated that though it is possible to develop a comprehensive list of indicators, it is much more difficult to develop a set of indices adequate enough for the effective evaluation of water projects and as was stated above, case studies clearly show that in the past decision-makers have overlooked or underestimated some adverse impacts which have rendered projects less advantageous or more costly.

Subsequently, Unesco and the UNEP created a joint project as a follow-up to A.3.2., to provide for practical management purposes an integrated methodology for the evaluation of the effectiveness of environmentally-sound management of water resources and the state of the water-related environment in river basins, for the benefit of managers and decision-makers.

The term practical management purpose includes all activities within and related to planning, design, construction, and management of river basin projects.

By integrated methodology it is to be understood that no endogenic factor of the system to be worked on and no factor imported into the system in connection with the planning idea should be *a priori* neglected. Thus all economic and social aspects are part of the system and should not be neglected as far as they are directly or indirectly related to the water-related environment.

The term manager and decision-maker includes all those involved either in the planning procedures or in the design and the implementation as well as the political partners who make the final decisions for the preparation of tasks or their implementation.

It was further understood by Unesco and UNEP that the methodology should be applicable to both the planning of new projects and the evaluation of existing situations.

It was further understood that the methodology should be suitable for any group and in any country, whatever the geographical situation, and for all types of water systems. Finally, it was agreed that the methodology should be applicable also in situations and countries where highly sophisticated mathematical tools are not always available.

An Expert Group was appointed and meetings were held in June 1985 at Leersum (The Netherlands) and in March 1986 at Unesco Headquarters in Paris. The Expert Group concluded that the A.3.2 Report formed a good point of departure for their activities and endorsed its fundamental concept of using indicators and indices to provide the necessary comparative basis for evaluation. It was clear, however, that these were not sufficient for methodological development, particularly of the economic, social and cultural aspects.

Goals and Procedure

The problems to be solved in practice increase in their complexity. When one type of water use reduces or even excludes other uses. There are seven broad types of water use (Table 1) which can be further subdivided into a variety of specific uses. Therefore wherever and whenever water projects are planned or realized care should be taken to ensure that the impacts are as small as possible and to keep open as many of the other options of use. This leads the planner:

- to attain the highest possible economic benefit with a minimum impact and disturbance, and

- as far as possible, to maintain the systems in their undisturbed natural state.

In certain situations man-made impacts have already distorted the original situation to a high degree with only meagre or even negative economic results, whilst the transformation of economic benefit into socio-economic and cultural values may be lacking.

In such cases the systems must be analyzed and developed

- to either improve efficiency, or

- to restore to a certain extent the original, natural situation.

Main types of Water Use	
1. Energy	
2. Recreation	- scenic - water sports - fishing (hunting)
3. Transportation	
4. Nutrition	- food - food production (irrigation) - agro-industrial water supply
5. Production	- industry - fisheries
6. Water source	- diversion - groundwater replenishment
7. Processing	- self-purification efficiency for waste treatment

The final task of the Expert Group was to develop a methodology for the assessment of the actual state of water related environments and the evaluation of the broad ecological and economical characteristics of water projects.

Basic Approach and Definitions

The action of man upon nature can also be seen as the activity of the human system within another system (the natural system) to extract natural resources from nature and transform them into economic products. Both systems in this case react with each other to form a system of higher order.

Let us first see what this System looks like.

The action of climate upon the geological substrate forms the raw soil which supports plant communities. The plant community in conjunction with the climate and the geology processes the raw soil into soil, influences the climate by feedback reactions and also produces food for the fauna. This combination of climate, geology and biology is an active ecological system whose character develops from the integration of its elements and, once established, undergoes only minor changes in the course of time (Figure 1).

When man enters the field, the ecological system is expanded and becomes also an economic system requiring rules, regulations, patterns, for the proper behaviour of its patrons and, therefore, needs social components, which in turn are governed by cultural and spiritual components.

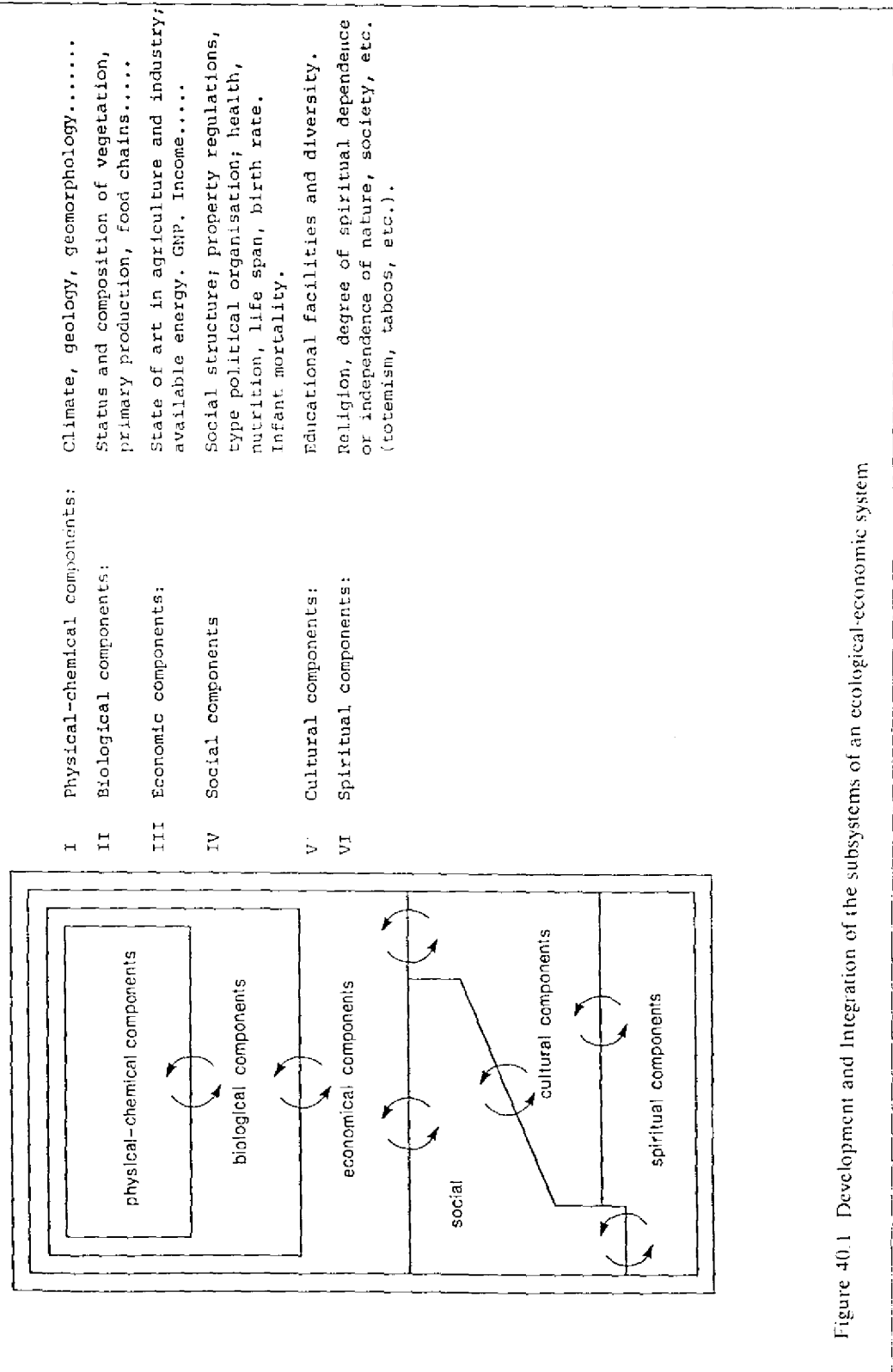


Figure 40.1 Development and Integration of the subsystems of an ecological-economic system

Such a system of course is a relatively complex structure, consisting of thousands of components which characterize it by their presence, by their quantity and quality as well as by their interactions (Figure 2).

Not all of the components can be observed. To describe the system it is necessary to select some either individually or in combined form, by their quality or quantity or by their behaviour. Such components can be used to indicate the state of the system and they are then called indicators.

For management purposes, for evaluating the state of the system or for projections of development, it is necessary to set limits to changes. Such indicators are then called standards. Standards should be set in such a way that the stability of the system to which they belong is not irreversibly affected.

Finally, indices can be used to indicate the degree of change.

Theory of Use.

As has been pointed out, economy is the process of extracting natural resources and transforming them into goods with an economic value.

A closer observation is, however, necessary in order to obtain a clearer picture: climate, soil, vegetation, fauna, etc., when integrated, offer a variety of use potentials. For example, the use potentials of a water course can be navigation, fisheries, recreation, hydropower, etc. These potentials are latent.

On the opposite side is the human subsystem, with a certain population, historical background, professional diversity, cultural and social levels, available experience and skills. This human subsystem has certain needs, which are interpreted as demands, and according to a given situation, an attempt is made to satisfy one more of these demands by having recourse to nature.

It is important to know that only those demands can be satisfied for which there is a natural equivalent potential. And the use of the potentials should not be exhaustive. (Figure 3).

The result of the interaction between the human subsystem and the ecological subsystem is of two types: the first is the desired good, the other is the change left in nature by the activity. It is a negative product leaving the scars of the impact. These may be reversible or irreversible.

It should also be stated that the transformation of resources into economic goods is not the final result of the activity. Economic goods *per se* are meaningless if they cannot be transformed into goods of a higher order (social, cultural) or at least lead to an improvement in health, social or cultural goods (Figure 4).

Whether or not and to what degree the activities are successful depends on the amount of energy and professional skills, etc. available for the first transformation and on social stability, the effectiveness of administration, the soundness of the political, social and cultural philosophy, for the second transformation.

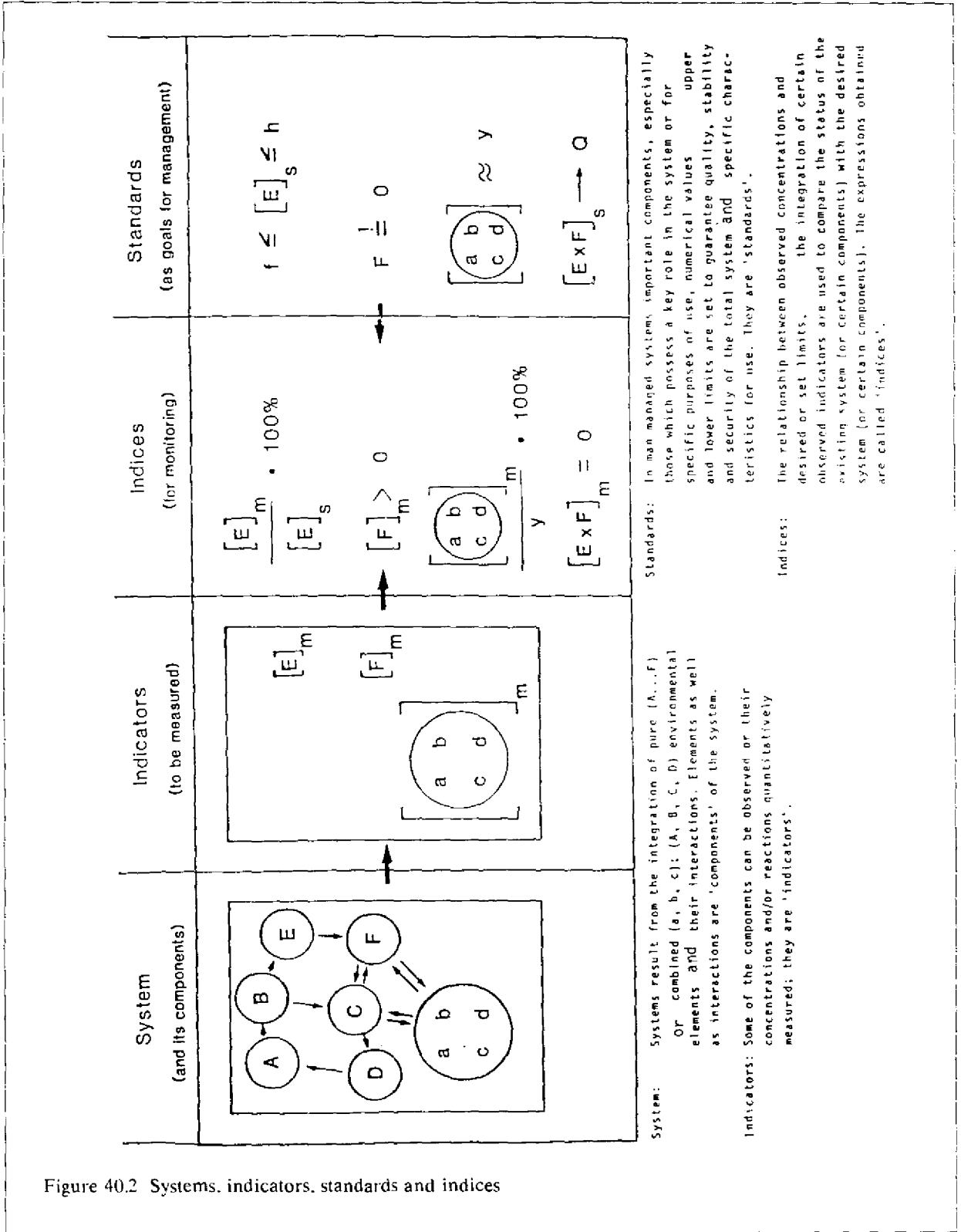


Figure 40.2 Systems, indicators, standards and indices

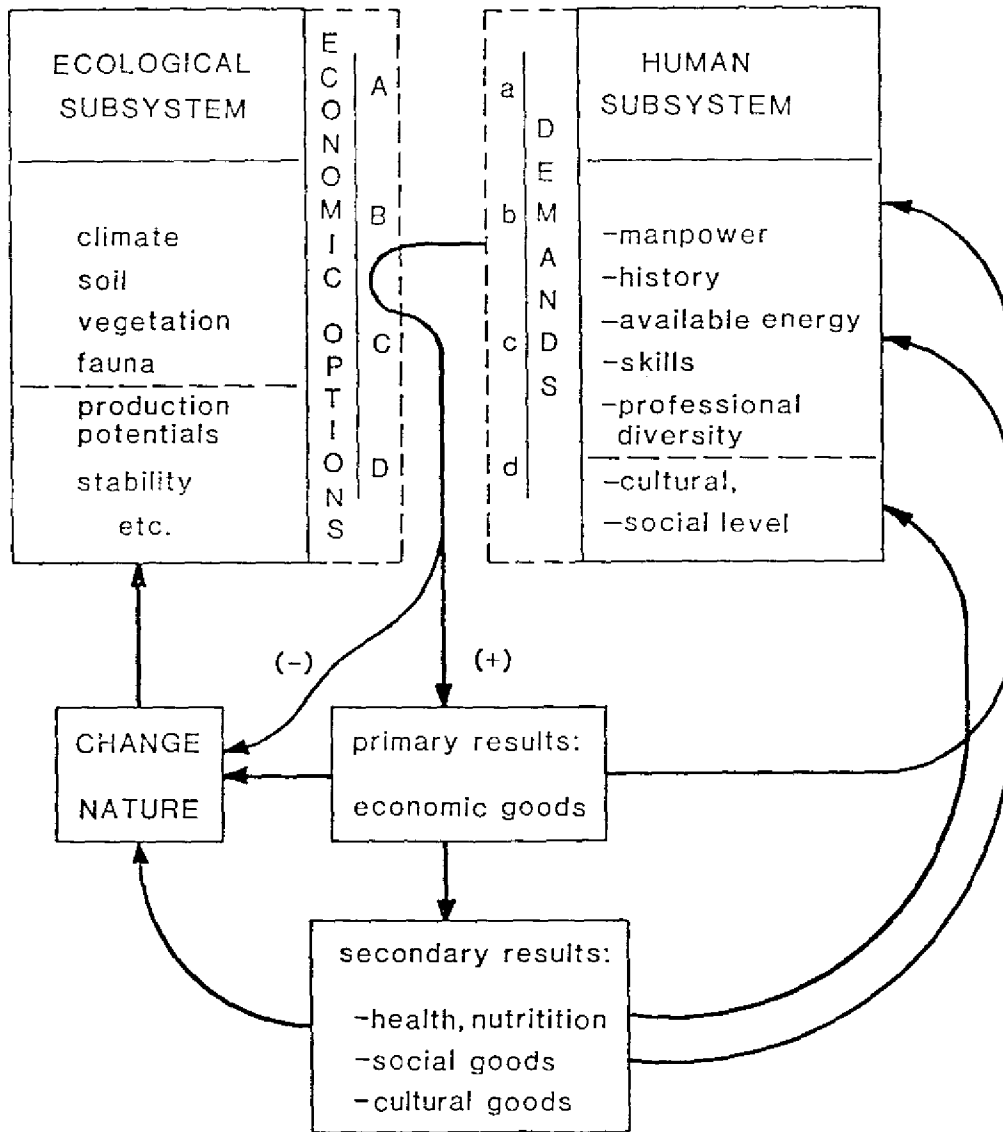
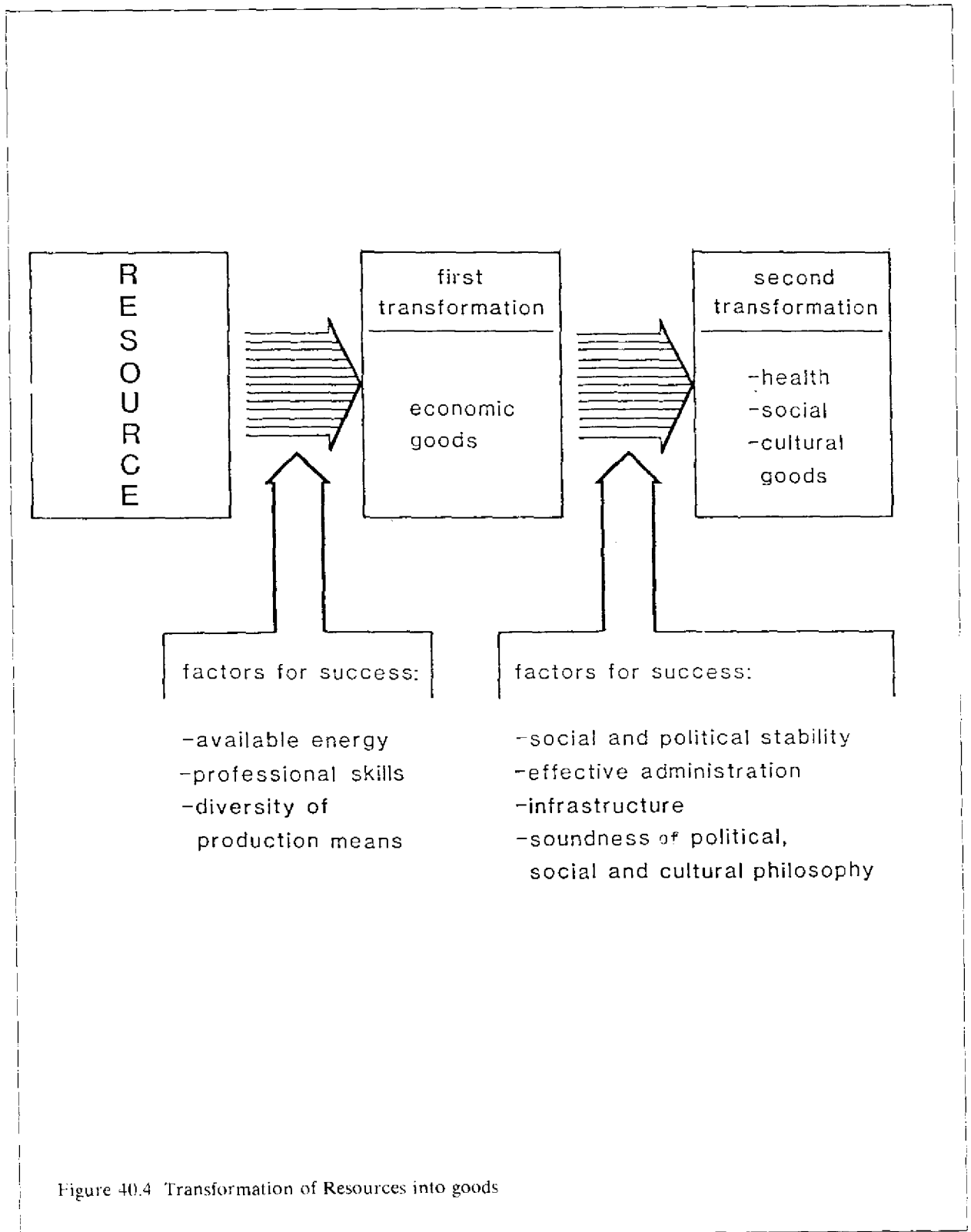


Figure 40.3 Integration of human and ecological subsystems



This completes the picture of the system. Briefly, it can be said that the effective use of an environment by man is on one side the result of options offered by nature and on the other the skills and ability to use these options and the skills and ability to transform them into goods of a higher level. Climate, on the one hand, and the political situation on the other both determine whether or not an engineering approach towards a hydro-environment will be successful. Also the evaluation of the state of an existing system and of the expected changes resulting from a planned water resources development, should also take into account the influence on the climate and not only the economic result or the goods produced. In a successful system, goods and negative changes in the natural system must be balanced.

These figures will serve to illustrate the background to be faced in connection with the development of many countries. Figure 5 shows the average life expectancy of man in different countries with extremes ranging between less than 30 years and 75 years. Figure 6 shows the energy consumption in the same countries which varies from only a few kilograms to about 20 t of stone-coal units per man-year.

Combining these two sets of information (Figure 7), it can be seen that there is a positive relationship between the two phenomena. Though there are wide differences between different countries, by a factor of five or even more, it can nevertheless be seen that the amount of energy available determines the average life span. The differences between the different countries arise from the variations of skills for making efficient use of energy, and of the political and administrative soundness and effectiveness of the system under discussion.

Mathematical Model

As defined earlier, economy is the use of natural resources, a use necessarily leading to changes in nature. When studying such systems therefore the relationship which exists between changes of the ecological subsystem and the economical (or human) subsystem must be brought to light. This means quantifying economic gains in relation to ecological losses.

In an ideal situation, there would be full economic use of the resource and no impact on the environment (point 0 in Figure 8). In practice, however, this is not possible, and some combination of less than full economic/social benefit and some environmental impact occurs (such as point A on Figure 8). Evaluation and judgement is made difficult by the fact that the economies of different countries offer a wide range of development and that in some cases the development potentials are relatively low due to the ecological situations.

The problem becomes one of determining the existing situation (point A, for instance, and then predicting the direction and amount of shift from point A to point B when the water resources project is completed and in full operation.

This process would be relatively simple if only physical/chemical/biological environmental impacts were to be considered since such components or indicators are in many cases quite easy to quantify and express in numerical values. But this is not the case of social and cultural benefits or losses which in many cases are difficult to identify, and of course much more difficult to quantify. It is vital, however, that as many of these impacts as possible are identified (indicators) and systematically evaluated, and that some quantitative statements (indices) be made of their relative importance.

The Selection of Indicators

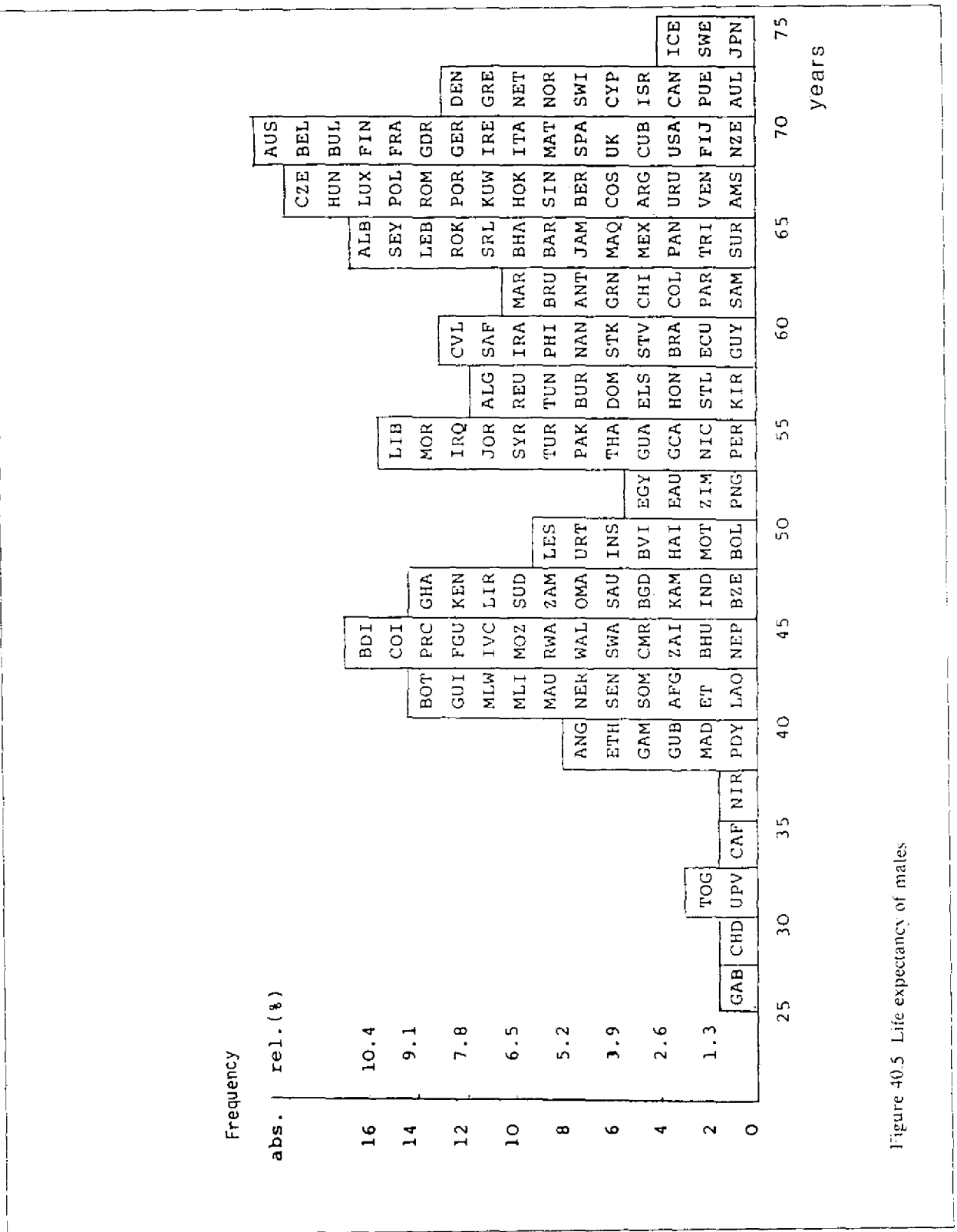


Figure 40.5 Life expectancy of males

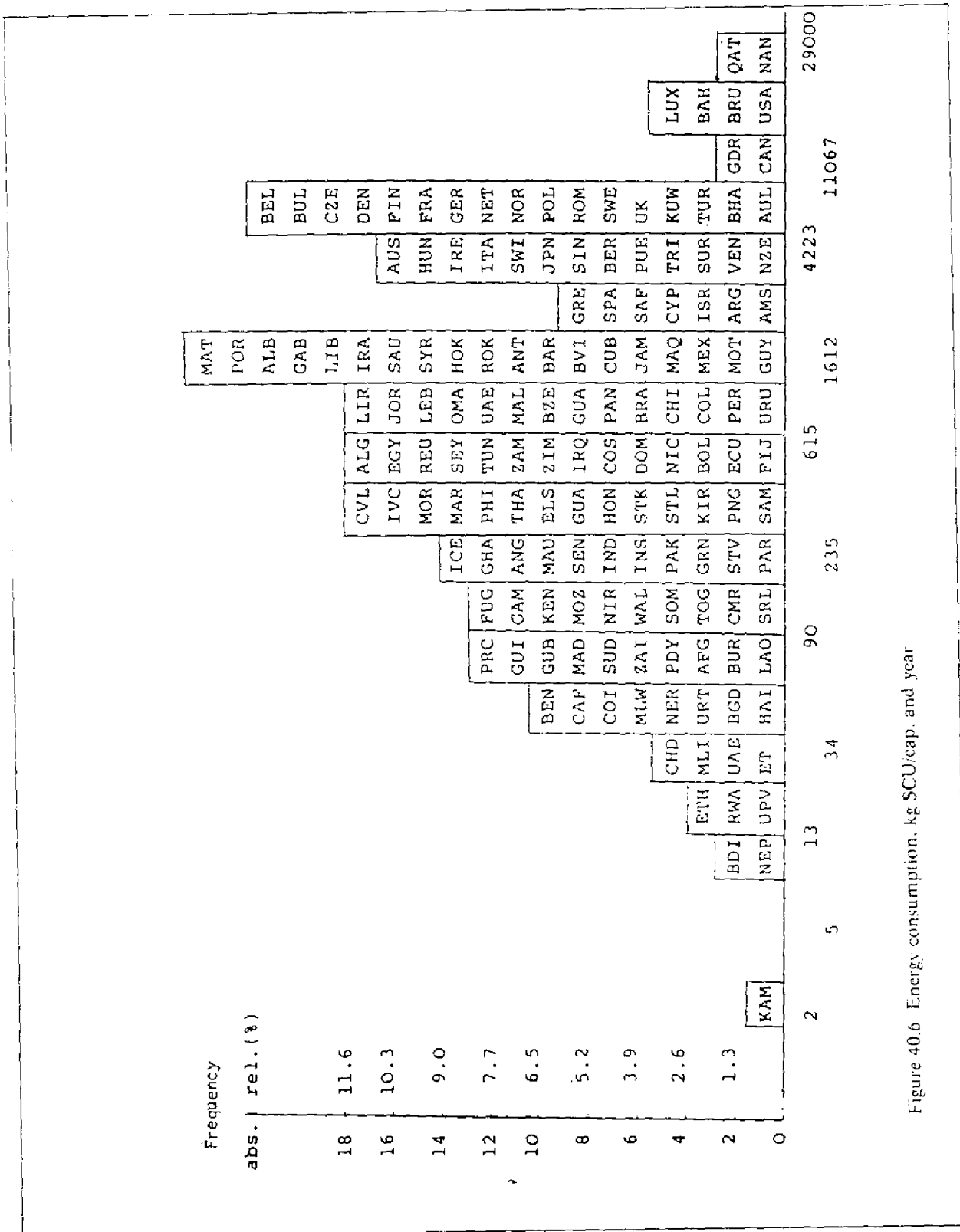


Figure 40.6 Energy consumption, kg SCU/cap. and year

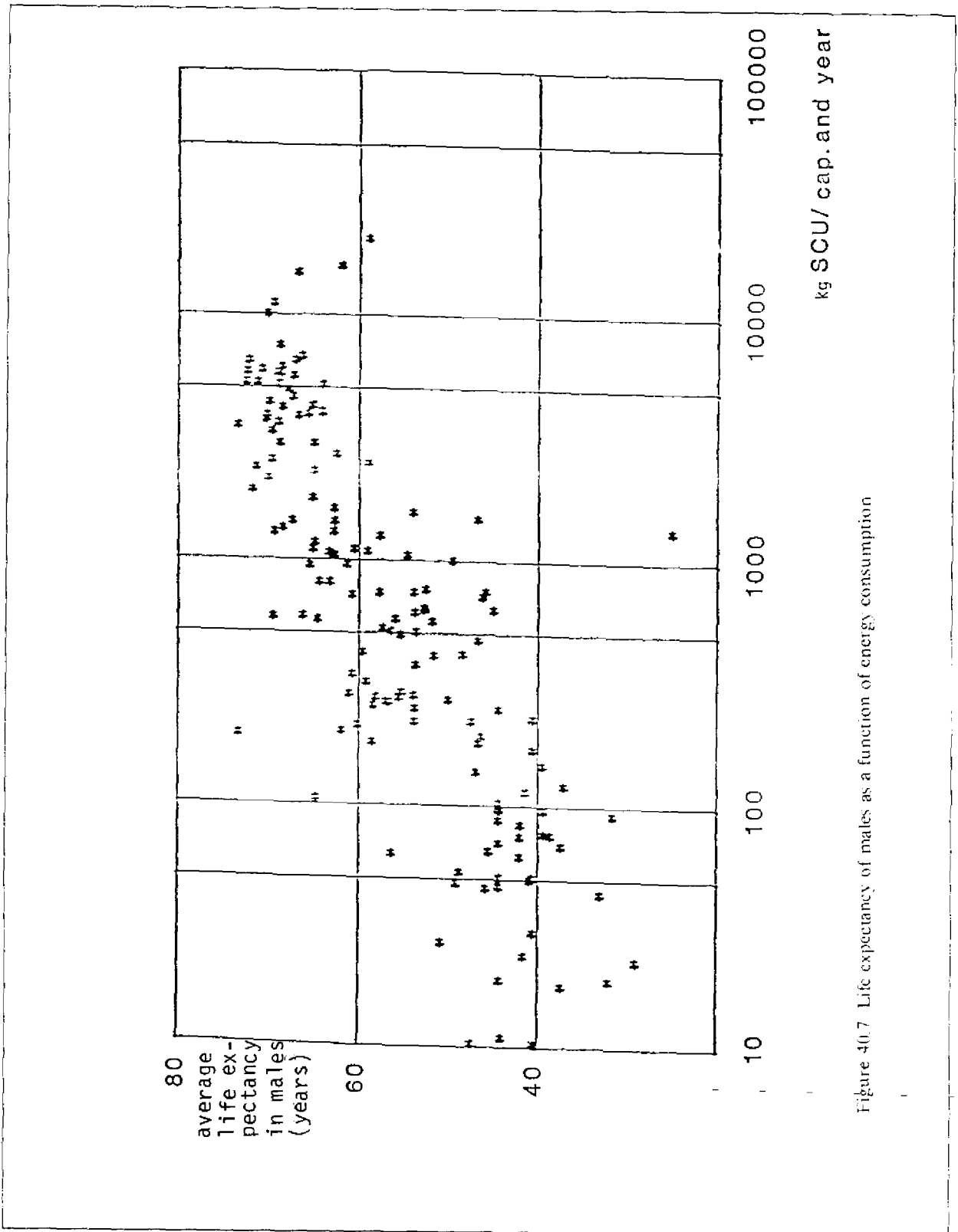


Figure 40.7 Life expectancy of males as a function of energy consumption

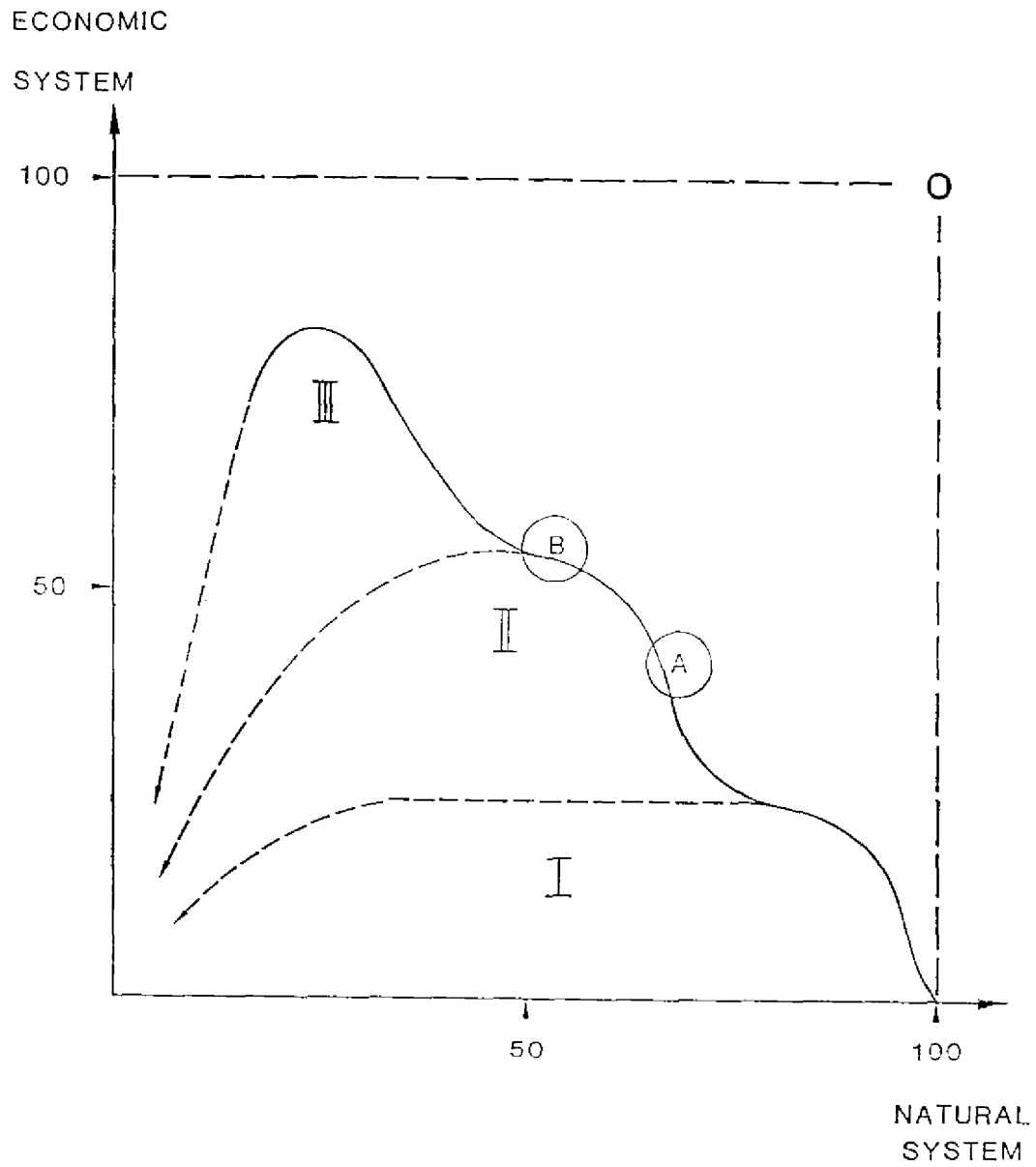


Figure 40.8 Transformation of natural systems into economic systems for three assumed different levels of economic potentials (levels of development)

Indicators are required to characterize both subsystems. It is advisable to use indicators which play a key role or give integrated results of the environmental systems and therefore can be used as tools for assessment and monitoring purposes. The selection of indicators should obey the following principles:

1. For practical application, the number of indicators should be limited;
2. They should be applicable to local situations as well as at the river-basin level;
3. They should be universal, which means that they should be more or less independent of the geographical region.

The list of indicators given in the text should not be understood to be obligatory. The selection is based on the understanding that they are either basic indicators of relatively high importance for other parts of the system, or indicators which play a key role in connecting other components, or are an integration of many components. Which indicators and combinations of indicators to select is a question to be decided for each situation. The experience and expertise of the analyst will help in making the final selection and may also in many cases lead to the introduction of indicators not listed here.

In the present approach the ecological indicators are:

- climate
- land and soil quantity
- land and soil quality
- water quantity
- - water quality, and
- - wildlife

For the human subsystem listed indicators describe:

- the economy of a project or a state
- the social situation
- the state of health and nutrition
- the cultural situation and
- the loss of other options caused by development of the option(s) selected.

In order not to go into too many details, only one group of indicators will be selected here for each subsystem. For the human subsystem and the social system, the following indicators may be representative:

- family income
- use of income

- statistical distribution of income
- population growth
- population migration

It will be the responsibility of the operator to select two or three of these indicators according to the problem further assessment.

In the ecological subsystem under the heading 'wildlife' for example, the indicators listed for an aquatic environment are:

- diversity
- endangered species
- fish production
- spawning potentials
- standing crop and its periodicity.

For further processing and evaluation the indicators selected must be quantified and integrated to form indicators of a higher order (second order). Then finally the second order indicators are integrated into one combined indicator, both for the ecological subsystem and human subsystem, which are then plotted as a function of the other. (Figures 9 and 10).

Transformation of Indicators into Mathematical Expressions.

The mathematical tools are developed in the UNEP/Unesco report "Methodological Guidelines for the Integrated Environmental Evaluation of Water Resources Development", Unesco, Paris, 1987, and only general information will be offered here.

To start the process, the selected basic indicators have to be qualified as for example 'maximum tolerable', 'minimum tolerable', or 'desired value' and then quantified by a mathematical number between 0 and 1; for example 0 being the lowest tolerable value and 1 being the highest. Then the normalized value for each basic indicator is calculated.

When this has been done the basic indicators for one group, for example for water quality or for the social situation, are integrated.

Finally, the second level indicators are integrated to arrive at composite indicators for both the ecological and the human systems. (Figure 11).

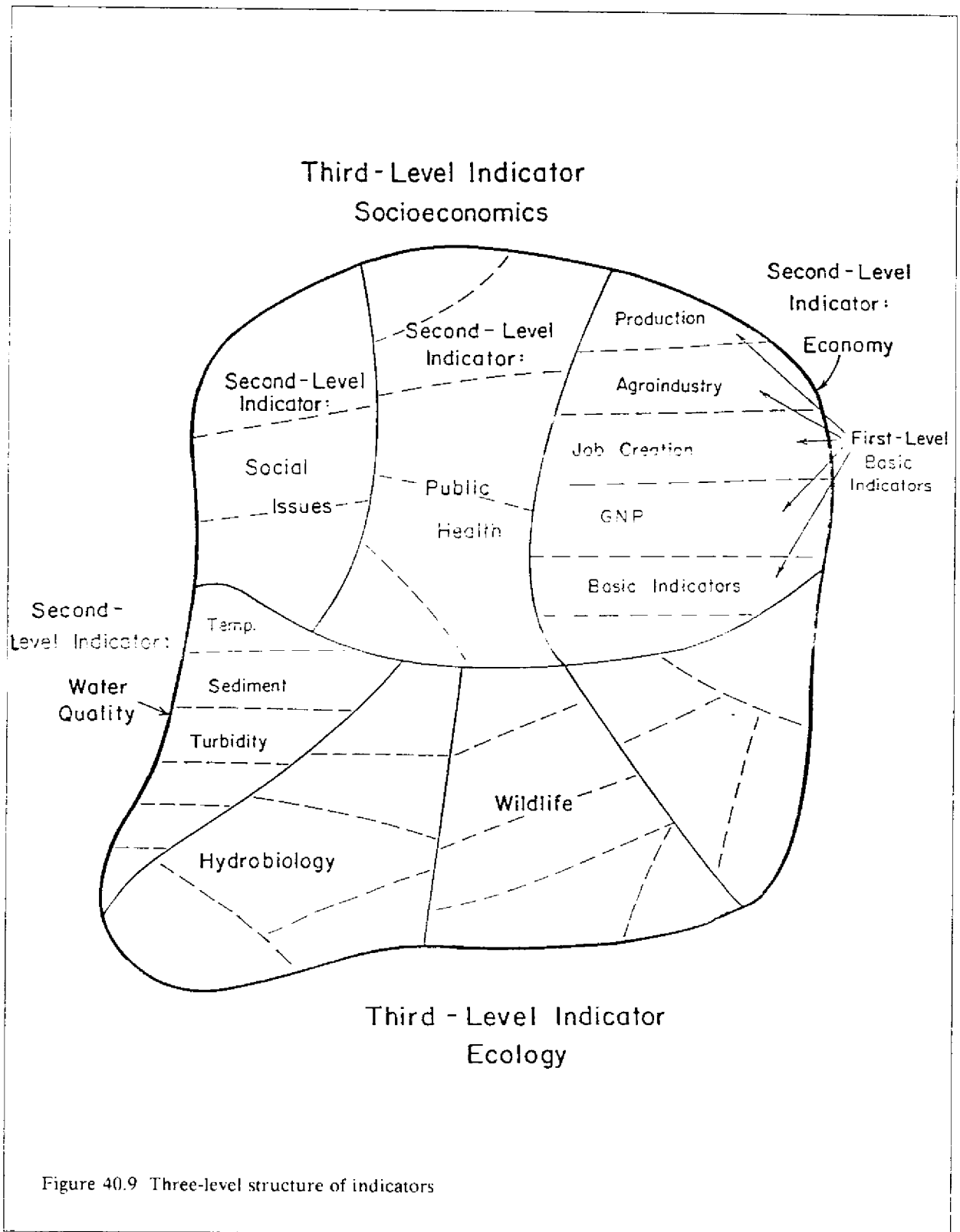


Figure 40.9 Three-level structure of indicators

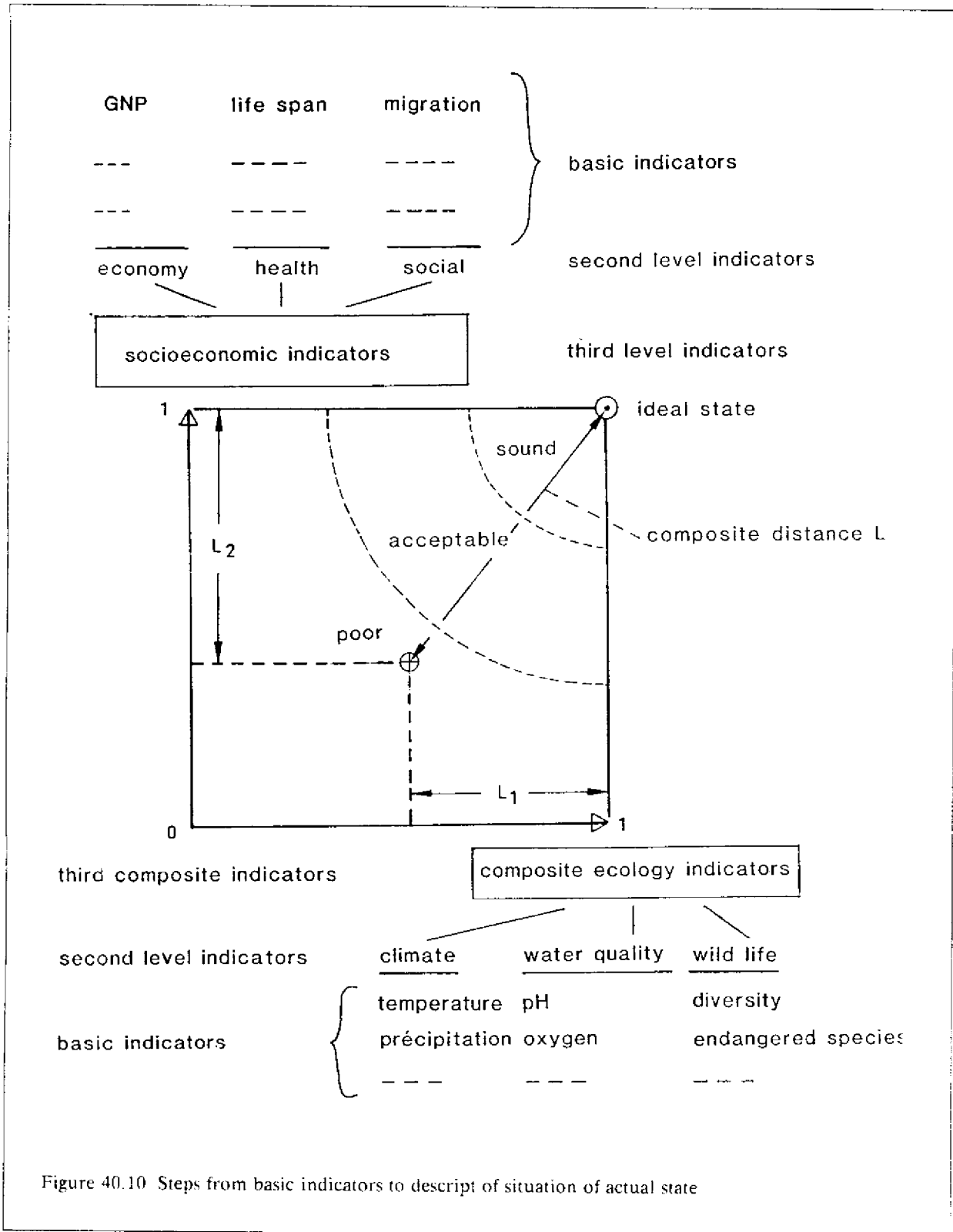


Figure 40.10 Steps from basic indicators to descript of situation of actual state

1. Normalizing basic indicators

$$S_i = \frac{Z_{i+} - Z_{i-}}{Z_{i+} + Z_{i-}}$$

2. Calculation of second level indicators

$$L_j = \left[\sum_{i=1}^n \alpha_{ij} \cdot S_{ij} \right]^{1/p_j}$$

3. Calculation of third level indicators

$$L_k = \left[\sum_{j=1}^m \alpha_{jk} \cdot L_{jk} \right]^{1/p_k}$$

4. Final composition between composite indicators for economy and ecology

$$L = \left(\alpha_1 \cdot L_1^2 + \alpha_2 \cdot L_2^2 \right)^{1/2}$$

Term for describing the third level indicator. What is important here are the weighing factors. By selecting limits for basic indicators the understanding of the situation and the philosophy of the operator are introduced into the mathematics for the first time.

By giving weights to the basic indicators, the philosophy of the operator is again brought into the mathematics. The term expresses the relative importance of the basic indicator. The parameter p reflects the importance of the maximal deviation. Here the mathematical result of second level indicator is influenced. Finally p is used again for calculating the mathematical expression for the third level indicator.

A final judgement is rendered possible by giving different weights for ecology and economy to define a point on the graph.

Critical judgement is needed and the solution we found must be applied in practice with great care because of the influence of the operator's own judgement, experience and philosophy upon the results. This can be very dangerous, and therefore it is highly important that only groups of experts should discuss and use this method.

It should be realized that even a group of the most intelligent specialists will be able to use the correct weights only in accordance with their own experience. In other words this model will not avoid all mistakes and it will still be necessary to proceed by trial and error. The mathematical tool however should lead to a quicker understanding and correct errors for tasks to come.

Summary

The purpose here was not to prepare some sort of recipe but to find a way to develop recipes. It was therefore decided to use the systems approach and to include not only ecological facts but also man in every system, and this not only with respect to his economy, since economy is only a tool to transform natural resources into social and cultural goods. Hence, social and cultural aspects have the same importance as all other aspects.

Indicators were listed for all the different facets of the ecological and human subsystems and it is believed that no engineering approach to nature should neglect the philosophical

1. Normalizing basic indicators

$$S_i = \frac{Z_i - Z_{i-}}{Z_{i+} - Z_{i-}}$$

2. Calculation of second level indicators

$$L_j = \left[\sum_{i=1}^{n_j} \alpha_{ij} \cdot S_{ij}^{p_j} \right]^{1/p_j}$$

3. Calculation of third level indicators

$$L_k = \left[\sum_{j=1}^{m_k} \alpha_{jk} \cdot L_{jk}^{p_k} \right]^{1/p_k}$$

4. Final composition between composite indicators for economy and ecology

$$L = \alpha_1 \cdot L_1^2 + \alpha_2 \cdot L_2^2 \quad 1/2$$

Definitions:

Z_i	actual value of basic indicators
Z_{i+}	maximum value
Z_{i-}	minimum value
S_i	normalized value of basic indicators (=index)
S_{ij}	actual value of basic index i in second-level group j of basic indicators
p_j	balancing factor
α_{ij}	relative importance (weights)
n_j	number of basic indicators in group j
L_j	composite index for second-level group j of basic indicators
L_{jk}	second-level composite index (ecology:k=1; economy:k=2)
p_k	balancing factor
α_{jk}	relative importance (weights)
m_k	number of elements in third-level group k
L_k	composite index for third-level group k
L_1	composite distance for ecology
L_2	composite distance for socioeconomics
$\alpha_{1,2}$	relative importance (weights) between conservation and development
L	composite index characterizing the actual state of system

Figure 40.11 Mathematics for evaluation of actual state

Hartmann

basis of the functioning of social and cultural systems, which in turn can only develop from the functioning of ecological subsystems.

Nature should not remain unused or untouched. Man should be permitted to use natural resources in a way which is described in the Genesis: And the Lord took the man and put him into the Garden of Eden to dress it and to keep it.

PAPER 41

CLASSIFICATION OF WATER SYSTEMS FOR THE ENVIRONMENTAL EVALUATION OF WATER RESOURCES DEVELOPMENT

L.W.G. Higler

Introduction

Classification is a technique to group elements that have characteristics in common which more or less are lacking in elements from other groups.

Classification of water systems can be performed on the basis of many criteria such as water chemistry, dimension, age, animal community etc. In this study an ecological basis for the classification is chosen.

Man's position in relation to water is predominantly a matter of ecology. By his dependence on water man is part of a worldwide biocenosis. Changes in the chemistry or physics of water systems are reflected by changes in ecological characteristics. Before such changes are inflicted on water systems one has to know which relationships exist and in what way these are affected by human activities.

The purpose of a classification of water systems is to indicate correspondences in structure and function of these systems by using abiotic and biotic characteristics in their mutual dependence. With such classifications any given water system can be classified to a certain extent and all class characteristics are applicable to that system. It sounds pretty good in theory, but in practice the classes overlap and exceptions are the rule.

This paper will indicate what general principles do exist and in which way a given situation must be judged to fit in a general pattern. Running and stagnant waters will be treated separately. This first division seems obvious; there are no or very few common features or species of plants and animals in both water types. One can think of a mountain stream and a moorland pool for example. There are, however, many situations where a boundary between running and stagnant waters is very difficult to find (the overlap of classes). The solution for these problems is an ecological approach as will be explained later.

Running waters

Running waters have one feature in common: during at least a certain period of time the water is running in one direction. That is all. But one cannot work with that. So generalizations must be made that include exceptions until there is a kind of statistical mean, that cannot be found in reality. Running water systems generally start at higher altitudes than small, oligotrophic streams with only a few species of plants and animals. In

its course to the sea (or lake) more water from different sources and tributaries joins the first (order) one, more nutrients enter the water and more species are to be found. Small streams become large rivers, lakes are filled and drained and ultimately water evaporates and adds to the rain or snow that feeds glaciers and sources. The hydrological cycle forms the basic explanation of hydraulics as well as a basis for physical and chemical processes in running waters.

In describing this scheme numerous exceptions turn up. Some streams start as rivers with a width of 15 m, some start as slow-running wet ditches with a very high nutrient content, some streams disappear in the soil and reappear at large distances or not at all, many streams dry out during months or sometimes years and so on. In Figure 1 an example is given of a scheme in which the environmental factors responsible for the situation at a certain place in a stream in The Netherlands are listed. The scheme is hierarchically scaled with, at the top, the conditions at country level, in the middle, those of the discharge area, and at the bottom, the characteristics of a single stream. In this scheme the dominating factor is the complex of hydraulic factors of which stream velocity is the manifestation.

Clusters of measurements from stations in running waters from all parts of The Netherlands have been encircled in the diagram and provided with names. Mountain streams do not occur in this country, but they can be incorporated on the right of the diagram. There is a gradient from right to left which leads from fast running to stagnant waters and a top-to-bottom gradient from large to small dimensions and ultimately to nearly terrestrial systems. The problem with the boundaries between running and stagnant waters are tackled in this diagram for slow-running waters and stagnant ditches and canals. The main factors for characterizing stations in running waters are: the *Hydraulic complex* and *Dimension*.

Scientists studying running waters have often pointed to a relation between factors that change from source to mouth and changes in the composition of fish or invertebrate communities. In generalized form it is known as the zonation concept (Huet 1949; Illies 1961; Illies & Botosaneanu 1963). From source to mouth one distinguishes more or less discontinuous zones, krenon --> rhitron --> potamon (upper, middle and lower course). Each zone is supposed to contain a characteristic fauna.

In 1980 a relatively new concept was published (Vannote et al. 1980), known as the River Continuum Concept. Here a continual change from source to mouth (from first order to nth order) is assumed in which fluvial geomorphic processes, physical structure, and the hydraulic cycle are linked to patterns of community structure and function, organic matter loading, transport, utilization and storage along the length of a river.

Both concepts contain valuable information and recently Statzner & Higler (1985; 1986) have combined elements from both, the essence of which is depicted in Figure 3. It is suggested that the complex of physical factors of flow (stream hydraulics) governs the zonation of stream benthos on a worldwide scale.

In Figures 2 and 3 no names of organisms have been given. This is impossible on a world scale because of zoo-geographical differences. A biological reference situation can only be given for a certain region. After description of the reference situation any given stream in the region can be compared with it and deviations from the reference situation can be analyzed.

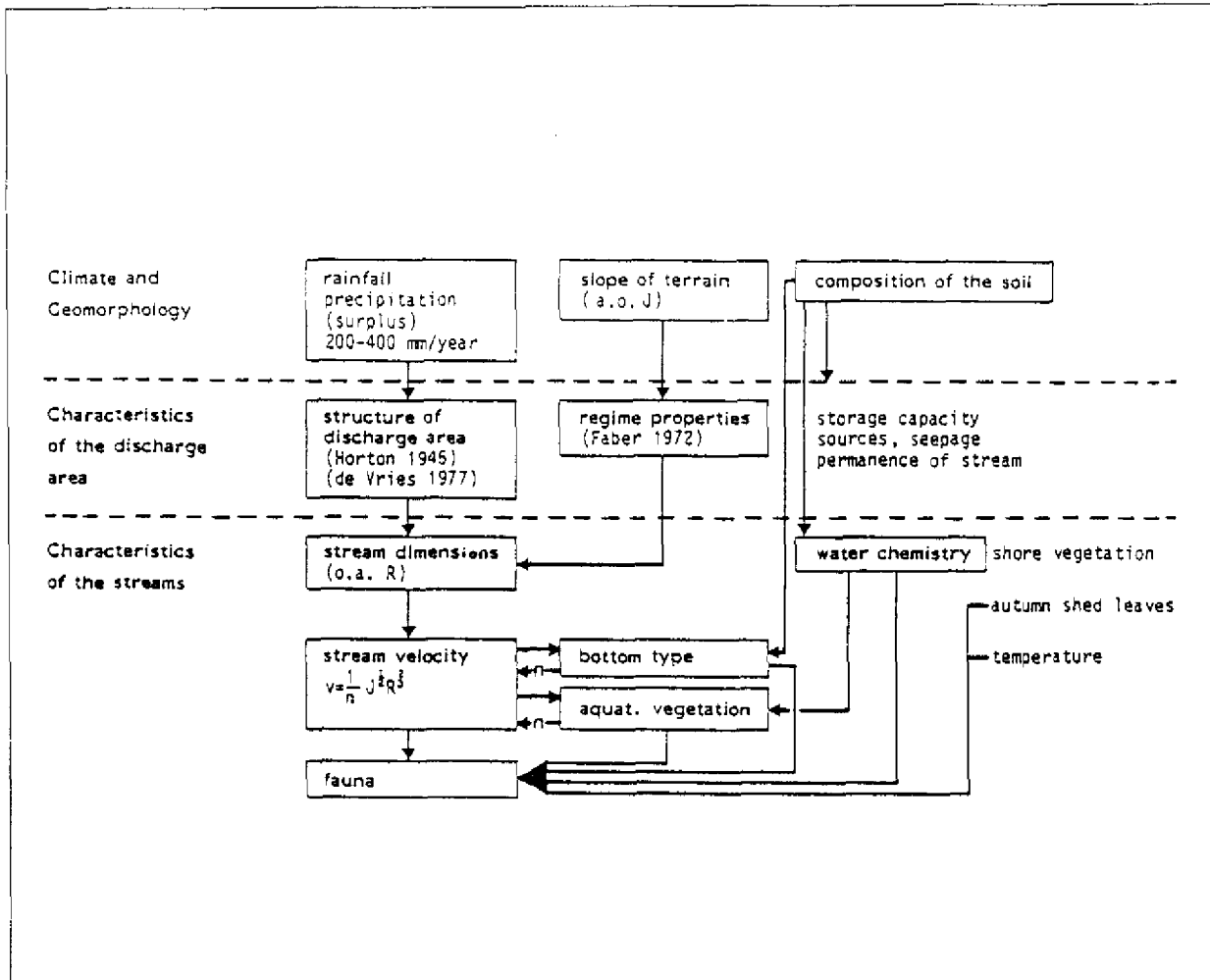


Figure 41.1 Scheme of factors controlling the conditions for the aquatic fauna in Dutch running waters (Higler 1981)

The Manning formula (in the square with stream velocity) offers a number of distinguishing marks of the station in a stream that have been used to characterize different types of running waters in The Netherlands. This is shown in Figure 2, where R is the hydraulic radius and Ct is a combination of the ground slope (J) and the roughness (n), called the terrain factor ($C_t = 1/n \cdot J^{1/2}$) (Higler & Mol 1984).

In order to find reference situations for separate regions a hierarchy of environmental factors can be used, not unlike the scheme of Figure 1.

Climatological regions have different types of precipitation regimes. This is the most important parting criterium, responsible for such phenomena as extreme high or extreme low temperatures, drought, ice cover, differences in discharge patterns, silting, etc.

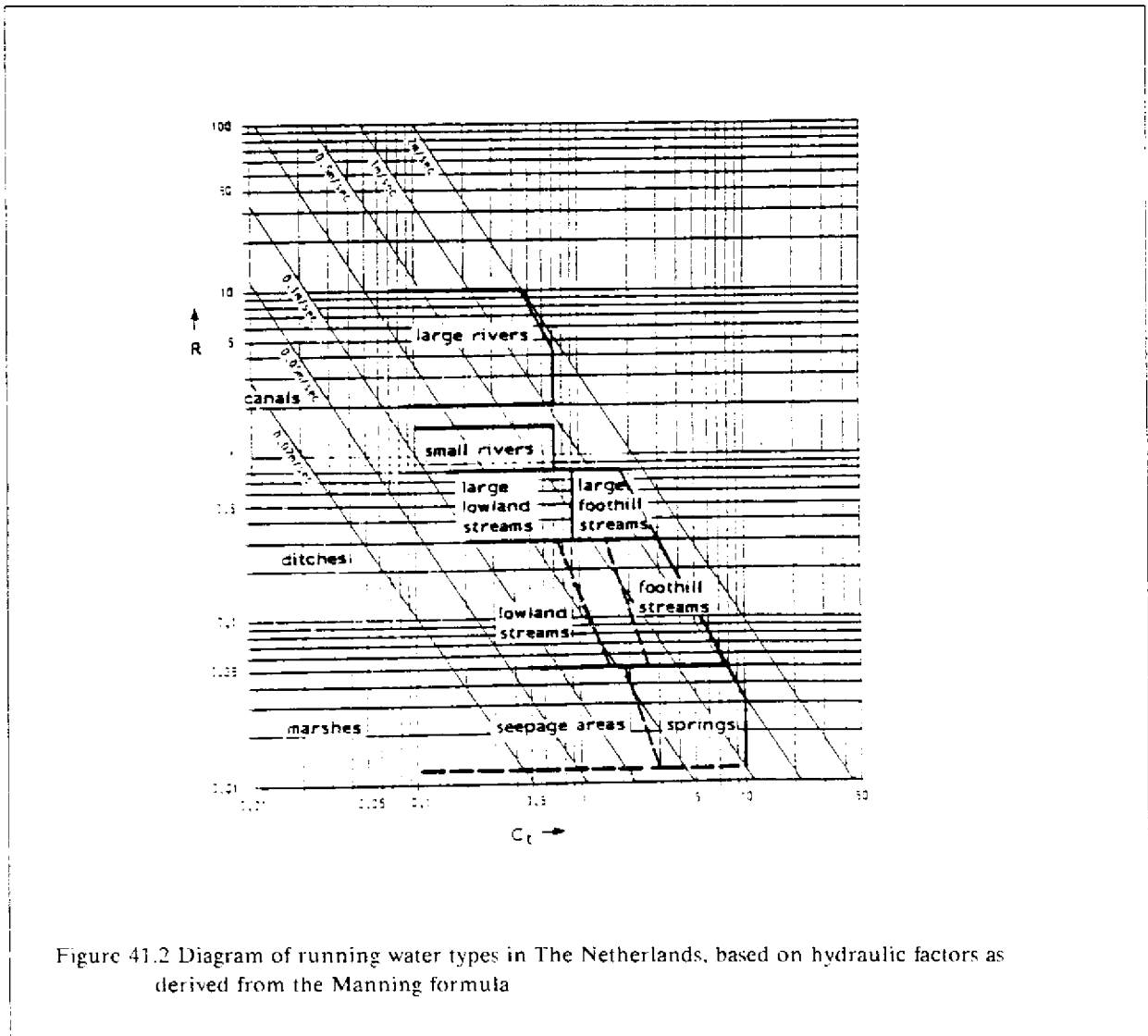
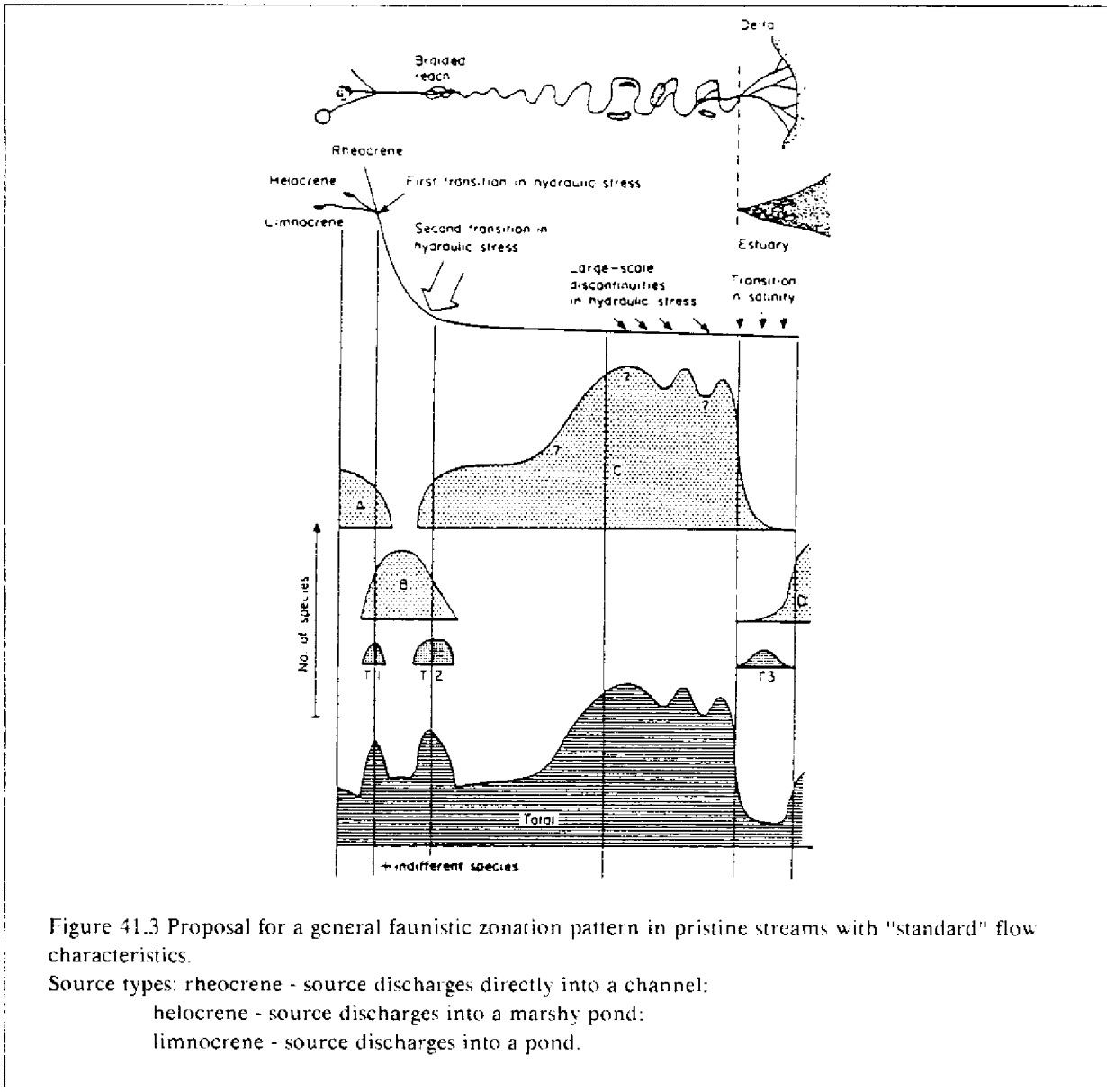


Figure 41.2 Diagram of running water types in The Netherlands, based on hydraulic factors as derived from the Manning formula

The geology and geomorphology determine the shape of discharge areas, but also the chemical composition of the water in a direct and indirect way. There are big differences in nutrient content when for example glacier streams are compared with lowland streams. The composition of the bottom material influences the pH and the nutrient content, and so does the vegetation in the valley. Streams can flow through lakes, interrupting the continuum pattern, and this situation is more common nowadays due to the presence of man-made reservoirs for energy generation or storage.

Some environmental factors are so dominant that no doubt exists as to their impact. Examples are drought and extreme cold, both natural conditions for certain climatological regions. Drought, however, can also be a man-induced phenomenon. Under extreme circumstances the bio-community will be impoverished to a set of organisms with a wide ecological amplitude and some specialized ones in addition.



The final report on the classification of water systems will give an extensive list of literature with the help of which regional "reference streams" can be constructed. For the European situation a fairly complete classification can be given. Lastly, many examples of man-induced changes in larger water systems will be given.

Not all of the components shown here can be or must be present in a stream. The species distribution in running water that starts with a helocrene and ends with an estuary is indicated in the example. Species occurring at the source (A) and in the reach of high slope (B) overlap at the first transition in hydraulic stress. Species of group B and species occurring in the stream after it has entered the flood-plain (C) overlap at the second transition in hydraulic stress, where pristine streams are frequently braided. Patterns in the

large river are somewhat speculative due to sparse information. In the brackish zone a third overlap is found between species of group C and the marine fauna (D). In all three zones of species overlap, few species occur which are solely found in these reaches of transition (T1, T2, T3). Species which do not characterize a zone are omitted. (Statzner & Higler, 1986).

Stagnant waters

No single factor dominates all processes in stagnant waters just as current velocity or hydraulics does in running waters. There are several important variables or characteristics, creating a multitude of possible combinations, many of which are known to exist.

A well-known classification is Hutchinson's, based on the *origin* of lakes (1957). He states that "It is more convenient to classify according to the general nature of the processes responsible for building, excavation and damming. Since the processes have acted locally, the resulting classification tends to be regional, certain types of process occurring in certain areas of the earth's surface". The same or related considerations have been elucidated already in the section on running waters; one has to accept this regionalization. Hutchinson discerns 76 types of lakes, grouped in the following classes:

- Tectonic basins (9 types)
- Lakes associated with volcanic activity (10 types)
- Lakes formed by landslides (3 types)
- Lakes formed by glacial activity (20 types in four subclasses)
- Solution lakes (5 types)
- Lakes due to fluvial action (12 types in three subclasses)
- Lake basins formed by wind (4 types)
- Lakes associated with shorelines (5 types)
- Lakes formed by organic accumulation (3 types)
- Lakes produced by the complex behaviour of higher organisms (3 types, beaver- and man-made)

Lakes produced by meteorite impact (2 types) Properties of lake ecosystems may be related to factors derived from the origin of the lakes, but not necessarily. In this classification shallow and deep lakes occur together within one type. This does not seem to be functional. The *depth* is the most important dividing characteristic, because all biological processes depend on solar radiation and its impact on production. For example, at a certain depth (between 6 and 12 m approximately) no macrophytes can grow and the numbers of algae are strongly reduced and also the presence of a thermocline (generally between 10 and 20 m) is of great importance for many processes in the lake e.g. oxygen regime. The functioning of the ecosystem depends more on depth than on the origin of the lake.

In general, limnologists have considered *morphometry* in which depth plays an important role as a good criterium for classification. Morphometric parameters used for classification whether individually or in combination are:

- Area (A)
- Volume (V)
- Maximum depth (z_m)
- Mean depth (z) ($z = V/A$)
- Length of the shoreline (L)
- Development of shoreline ($DL = L/2(\pi A)^{1/2}$)
- Ratio z:z_m

The works of Naumann and Thienemann in the first decades of this century are very important for an ecological classification. They used PRODUCTIVITY as a basis for classifying lakes into eutrophic and oligotrophic lakes. Naumann discerned six types of oligotrophic lakes, Thienemann considered one of these subtypes (dystrophic) as a third type in his classification. The main idea is that oligotrophic lakes have few nutrients and accordingly are a characteristic biocenosis of algae and invertebrates, differing essentially in species and total numbers from eutrophic lakes, where many nutrients cause other conditions. Apart from nutrients, factors like temperature regime, light penetration, detritus- and gaseous regimes influence productivity.

Okland (1964) summarizes 7 categories of parameters used for lake classification:

Climate (responsible for the first classification in 1901
(Forel) with the help of the temperature regime)
Morphometry
Chemical and physical properties
Sediment
Flora
Fauna
Productivity

Many factors are interrelated (but not always) and some are missing. The attention to lakes in classic (and most of the modern) limnology has neglected shallow water systems, except the more spectacular ones with large surfaces. In shallow waters with depths ranging from decimetres to a few metres, conditions are different from those in deep waters. It is easy to see that daily fluctuations in temperature (and consequently oxygen content) are much higher, which influences many processes in the biocenosis. Shallow waters can be temporary, they can freeze to the bottom, they can be filled with macrophytes and relatively small disturbances can have enormous impacts. For these and other reasons a separate treatment of shallow and deep waters seems justified.

Verdonschot (1983) gives a very useful scheme of factors that influence conditions in surface waters (Figure 4). The scheme is hierarchical and resembles Figure 1. Although this scheme is intended for the Dutch situation, it is obvious that a much wider application is possible. In the final report, many examples will be treated in such a way that a better scheme or a better completion of the scheme can be given.

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Fig. 4. Relationships of dominance in surface waters

NATURAL PROCESSES	COMPONENTS	ANTHROPOGENIC PROCESSES
Climatic changes (long-term changes)	Climate (e.g. precipitation, temperature, wind, light)	Atmospheric pollution (influence on temperature, precipitation/acid rain)
Changes in the balance of import and export by erosion/deposition. Changes in the balance of mineralisation/accumulation of organic matter	Soil (e.g. sand, clay, peat)	Discharge/supply of substrate (dredging, filling up, organic pollution)
Erosion or deposition by wind and water (e.g. bank-erosion and meandering)	Profile (the natural shape)	Changes in profile (e.g. digging, regulation)
Changes in water table due to variation in precipitation; changes in mineral composition of soil due to erosion	Water (quantity and quality)	Watermark changes (waterwinning, drainage, infiltration) Eutrophication (agriculture, effluent discharges)
Dynamic processes of the equilibrium, succession and degeneration (changes in the mineral cycle, waterconsumption etc.)	Plants (Bacteria, Fungi, Algae, Higher Plants)	Management (mechanical, chemical, biological) Shading (eventually planting)
Dynamic processes of the equilibrium, increase or decrease of transposition of organic material	Animals (Amphibia, Reptilia, Micro-, Meio- and Macrofauna, Pisces, Birds, Mammals)	Management, Fisheries

PAPER 42

TAMING THE FLOODS - ENVIRONMENTAL ASPECTS OF FLOODPLAIN DEVELOPMENT IN AFRICA

C.A. Drijver & M. Marchand

Summary

Africa's floodplains are key areas for the survival of millions of people. Presently, they are threatened with an irreversible loss of their natural resources, through the combined impacts of droughts, over-exploitation of soils and vegetation and the mismanagement of the water regime. To an increasing extent modern development programmes aim at manipulating water regimes. The taming of the floods causes radical changes in the floodplain ecology, leading to multiple environmental problems, affecting the very basis of development. In order to solve and prevent these changes, it is necessary to integrate ecological considerations in development policies, planning and design. In this paper the impacts of various hydro-agricultural and hydro-power projects on the environment are systematically reviewed. Principles for a more appropriate Cost-Benefit Analysis are outlined comparing traditional floodplain resources exploitation with modern irrigated agriculture. Finally, three options for sustainable development and conservation of the African floodplains are reviewed.

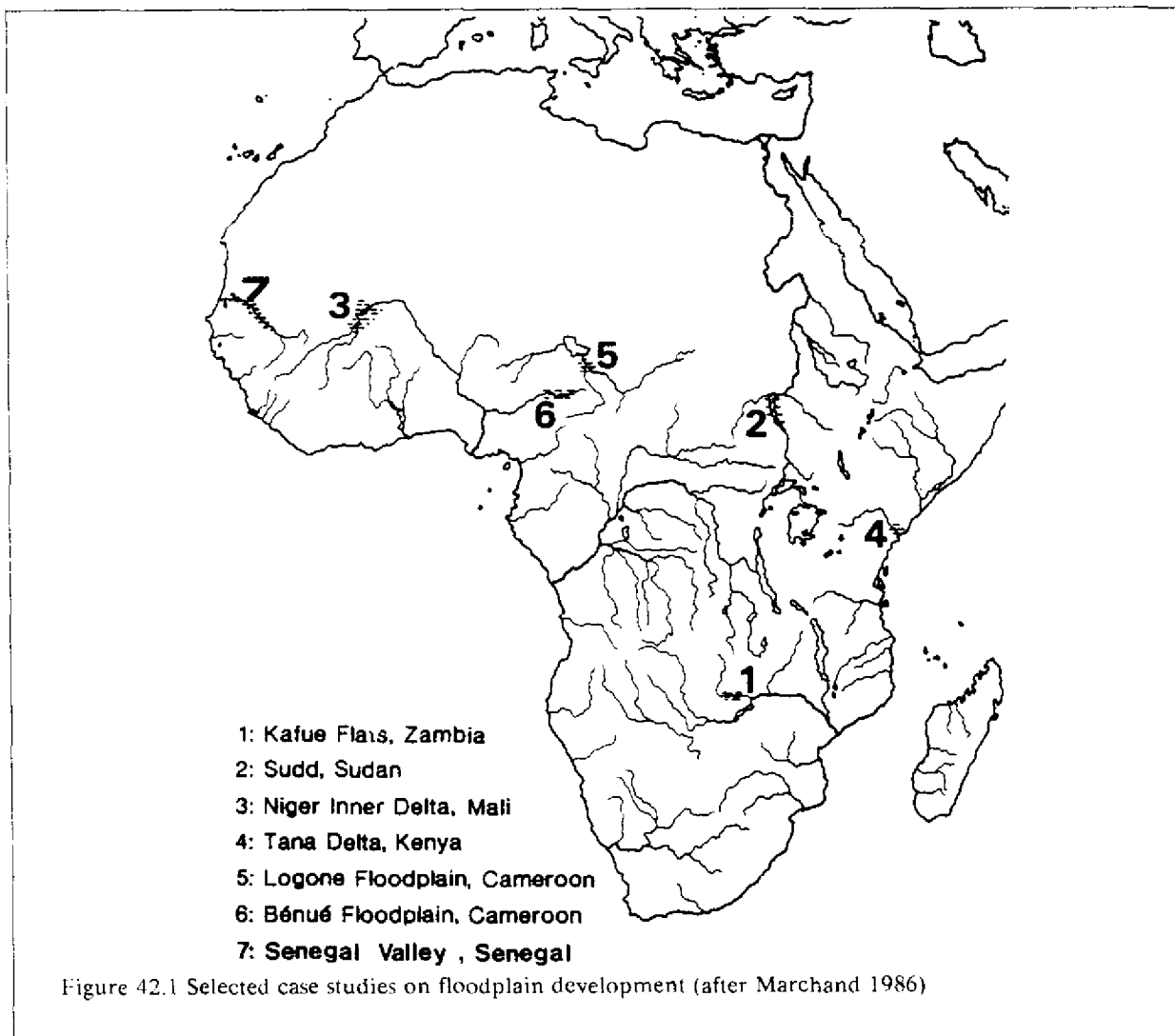
1. Introduction

This paper is based on a study carried out by the authors in 1984 and 1985 (Drijver and Marchand, 1985). It synthesizes experience and knowledge of environmental aspects of water management projects in seven African floodplains. The names and location of these case studies are outlined in figure 1.

Of the total African wetland area, almost half is formed by floodplains bordering large rivers. The case studies described in this paper are to a great extent representative of the 300 000 km² of the African floodplains.

2. Functions and values of the floodplain environment

At first sight, floodplains in Africa seem sparsely populated and relatively under-exploited. However, a closer look reveals that millions of people are dependent on them for their survival. The seasonal flooding by the rivers prevents the floodplain from being permanently inhabited by large numbers of people who, instead, build their dwellings on the margins and higher parts of the plain or adopt a semi-nomadic way of life. They use the natural resources in a variety of ways, as shown in Table 1. Most of the traditional exploitation modes, like fishing, cattle raising and flood recession agriculture are dependent on the timing and duration of the floods and hence conform to a strictly seasonal pattern.



Fishing

When the floodplain is inundated the fish are widely dispersed and fishing activities are restricted. Early in the flood season spawning has taken place, and the young fry benefits from the abundance of food and the wide expanse of shallow waters. When the water starts to drain back into the main channels, the fish concentrate in creeks and lagoons. During this period a high catch is obtained with a minimum effort and investment. Baskets, nets and weirs are used, sometimes in combination with specially constructed ditches. A second fishing peak occurs at the beginning of the next flood when the water level starts to rise again and the fish migrate to their breeding grounds on the floodplain (Welcomme, 1979).

Cattle raising

With the advance of the severe dry season, the Sahelian upland pastures dry out completely and cannot provide sufficient fodder for herds to survive until the onset of the

Table 1. Floodplain resources and their use (modified from Symoens, Burgis and Gaudet 1981)

season	available resources	human exploitation
non-flood period	groundwater	drinking water and irrigation
	surface water of river, creeks and pools	for homestead gardening fishery, irrigation, harvesting of wild rice, washing cattle,
	vegetation	gathering of fuel and construction materials hunting and tourism
	wildlife soil	recession culture and rainfed agriculture
flood period	groundwater	drinking water
	surface water vegetation	floating rice cultivation, fishery, harvesting of wild rice, gathering of construction materials
	birds and wildlife	hunting and tourism

next rainy season (Kessler and Ohler, 1983). At that time, the water level on the floodplain is falling and fresh grass shoots up on the wet soil. The herds come from distances of 250 km or more to occupy the floodplain pastures for a period of two to three months. Obviously, the floodplains are of crucial importance for the proper functioning of the transhumance herding system that is characteristic of Africa's semi-arid regions such as the Sahel.

Floodplain agriculture

Floodplain agriculture consists of three typical cropping systems. When the water starts rising, varieties of floating rice able to survive high flood depths are planted. At the end of the flood season a special variety of sorghum is planted in the wake of the receding water, adapted to the conditions of a watertable which gradually drops to about 2,5 m (Meurillon and Pontanier, 1983) Late in the dry season the river banks of the main channel are exposed and planted with various garden crops.

These three forms of agriculture have in common that they make an optimal use of the available water and the fertile sediments that are deposited by the river, and that they only require the input of the existing labour capacity and skills of the local communities. Capital inputs are hardly necessary. Although production levels are lower than those of intensive high-input farming systems, they are nevertheless fairly high in comparison with traditional types of rainfed agriculture (Anonymus, 1978). Moreover, harvesting takes place during critical periods in the dry season when there is no production on the rainfed soils of the uplands. Thus, floodplain agriculture is a prerequisite for a year-round food supply.

In respect of their combined production of fish, meat, milk and crops, floodplains should be regarded as multifunctional productive ecosystems that play an essential role in the traditional land-use systems and survival strategies of many people in Africa.

These traditional systems often coexist with valuable natural ecosystems. Many floodplains like the Niger Inner Delta, play a key role in international bird migration systems and support millions of Palearctic waders and ducks during several months of the year (Roux 1971 a). Some areas still support a rich wildlife, including rare and endemic species. Large populations of wild ungulates have either developed ecological adaptations to the floodplain environment or impressive migration patterns which enable them to survive (Marchand, wisse and Drijver; Mefit Babtie, 1983 a).

Due to the recent drought periods in Africa, these systems are under great stress. However, it is expected that their natural resilience is large enough to enable a rapid recovery once normal hydrological conditions return.

3. Impacts of hydro-agricultural projects

Three main groups of hydro-agricultural development projects can be distinguished:

- damming of rivers and tributaries
- flood control measures and poldering on the floodplain
- canal construction

A complete description of the physical impacts, real or forecast, for the seven case studies is beyond the scope of this paper. Only a qualitative review of the most important impacts will be presented here.

Water quantity changes

In general, upstream damming, canal construction and subsequent water use for irrigation purposes, lead to a reduction of the volume of water available for flooding. Also the timing and duration of the floods may be changed; in the extreme the floods may even disappear completely (Fig. 2). This will in all cases adversely affect floodplain fisheries (which are very sensitive to the timing of the floods), the floodplain pastures (less inundation generally induces the growth of less palatable grasses) and the flood recession crops (water availability becomes a problem and in the long term soil fertility declines due to a reduction of silt deposition). It goes without saying that the construction of large dams can exert an adverse influence far downstream in the floodplain and attain the coastal zone (Ganne, Flemming et al).

In the case of the seven case studies presented here, water manipulation is expected to cause a reduction of true floodplain habitat of 10 to 100 percent (Fig. 3).

Water quality changes

River impoundment upsets the silt balance of the river. The storage dam retains large volumes of silt, leading to a subsequent reduction of storage volume. Reduced silt loads downstream deprive the floodplain from natural fertilization and sedimentation. This endangers the sustainability of traditional flood recession agriculture.

Secondly, river water can become contaminated and eutrophicated resulting from agricultural projects upstream. Agricultural waste waters are often polluted with nutrients (nitrates and phosphates) and pesticides.

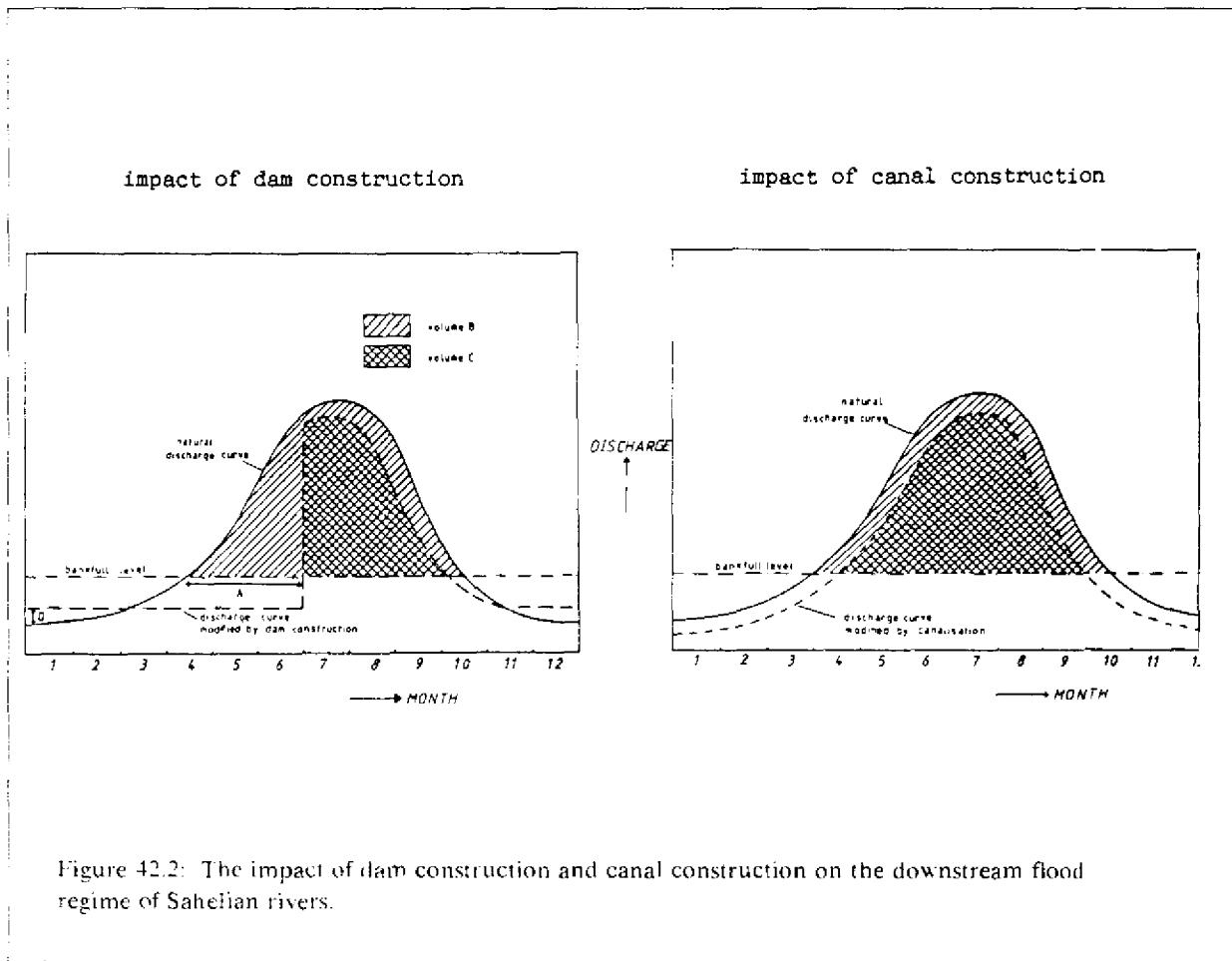


Figure 42.2: The impact of dam construction and canal construction on the downstream flood regime of Sahelian rivers.

On-site impacts

The most extreme example is that of a complete conversion of the floodplain habitat into agricultural land. It will be obvious that this will leave little or no perspective for the traditional fishery, cattle raising or flood recession agriculture. Tables 2 and 3 illustrate the impact of polders on traditional exploitation systems. For cattle and wildlife not only the loss of floodplain area is detrimental, but also the obstruction of their migration routes to remaining pastures by dykes, canals and buildings (Ecosystems, 1983).

Secondary and social effects

Many other activities may follow in the wake of the hydro-agricultural projects. In turn, these activities will have effects on the ecosystem and on traditional cultural patterns, the so-called secondary effects. The most predictable effects of increased pressure on the remaining natural resources through population increase (i.e. deforestation, wildlife disturbance, poaching, etc.). Another secondary effect is the commercialization of traditional production systems. In general, hydro-agricultural projects induce infrastructure improvement, accelerating the process of incorporation of traditional socio-economic systems in the national or international economy. Natural resources, such as fuel-wood and

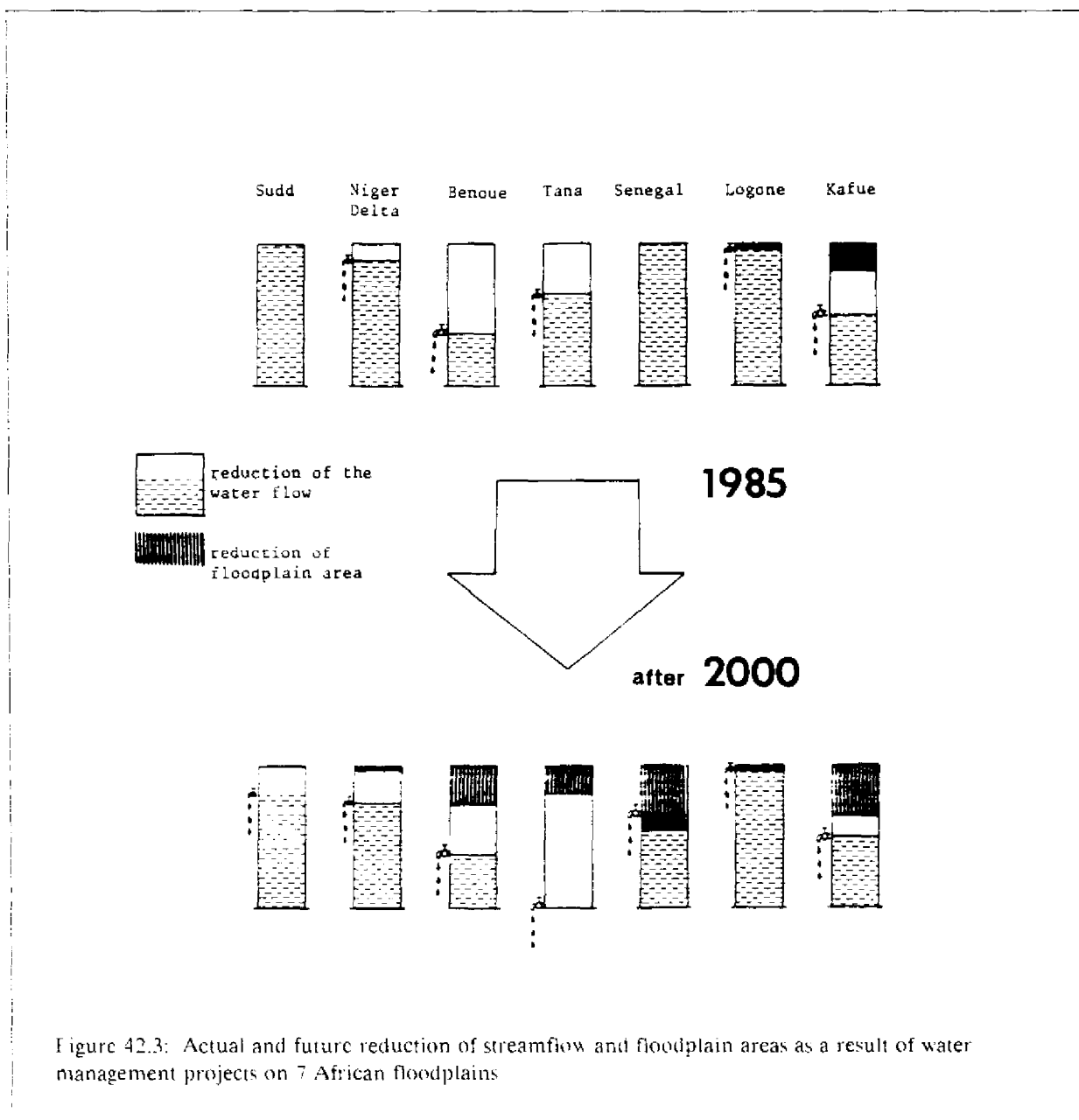


Figure 42.3: Actual and future reduction of streamflow and floodplain areas as a result of water management projects on 7 African floodplains

fish, become regional economic assets which attract people from outside. Traditional cultures are upset and over- exploitation of resources is likely to occur or, increase.

4. Lessons learned

4.1 Impacts

The social and economic importance of floodplain ecosystems for the local population and their great value for nature conservation are to a large extent determined by their water regime.

Table 2: Loss of flood recession agriculture due to polders

Floodplain	Bénoué	Kafue	Logone	Niger	Sénégal	Tana
Loss of area (ha)	max 15 000		3 465		max 87 510	200
Loss of production (t year ⁻¹)	2 250		3 181		35 000	300

Table 3: Impact of polder lay-out on cattle grazing

Case Study	Bénoué Valley	Kafue Flats	Logone flood- plain	Niger Inner Delta	Sénégal Valley	Tana Delta
Effect						
Loss of floodplain grazing land	+	++	++	++	++	++
Obstruction of migration routes	+	?	+	+	++	+
Annual precipi- tation (mm)	1000-1200	800	700	300-600	300-600	600

++ = important
+ = less important

Large-scale hydro-agricultural development and the accompanying promotion of intensive exploitation of the African floodplains always have significant and often unexpected effects on their ecological functioning. Generally, these impacts result in a deterioration of the traditional production systems and of the floodplains' capacity to support migratory birds and wildlife.

In five of the present case studies these social and environmental risks were not assessed and taken into account in the feasibility studies for hydro-agricultural development.

4.2 Better cost-benefit analyses

One of the steps towards a more rational and sustainable development is the integration of environmental aspects in cost-benefit analyses. This will enable a more realistic judgement of pros and cons. As an example, in Table 4 is shown a comparison between an

older type of cost-benefit analysis and a newer, more integrated one which takes into account a floodplain's multi- functionality and its capacity of self regulation.

In the old-type, cost-benefit analysis, the economic benefits of modern rice cultivation are compared with the original level of only agricultural crop production and only part of the costs of measures to obtain this modern production level. Sustainability and side effects on other sectors are not taken into account. From the figures one might get the impression that the transformation to modern rice culture is an easy and economically very attractive enterprise without major risks.

In the new, more integrated cost-benefit analysis, the economic benefits of modern rice cultivation are not only compared with the original level of agricultural crops, but also the losses (induced by the project concerned) in the field of cattle raising and fisheries are taken into account (multi- functionality). In order to compare rice, meat, milk and fish two basic dimensions are chosen: proteins and energy.

Normally, productivity is given per unit of cultivated area. In the region of our example (the Inland Delta of the Niger in Mali) however, more conflicts arise due to the limited availability of water than to land. It is therefore interesting to know which production system makes the most economic use of this limited resource. Hence, productivity is more properly expressed in terms of proteins and calories per unit quantity of water. It can be seen that the old method (expressing productivity per ha) underestimates the productivity of traditional land use in the Niger Delta.

A third aspect is the floodplains' capacity of self regulation. In the traditional floodplain production systems the fields are irrigated by river flooding, nutrients are deposited with the fertile silt. After recession of the floods, crops can be planted without the necessity of weeding. the seasonal inundation of grazing areas prevents persistent overgrazing and desertification and floodplain dynamics prevent bilharzia and aquatic weeds from becoming major problems. All these spontaneous regulation activities are taken care of by nature, free of charge. In modern large-scale irrigation systems much of these activities have to be taken over by project- and farm- management. In many cost-benefit analyses the costs and complexity of environmental management are seriously underestimated.

Last but not least, the sustainability of production systems should be integrated in cost-benefit analyses. For modern irrigation projects this implies that the recurring costs of rehabilitation have to be taken into account.

It may be concluded from Fig. 4 that the improved cost-benefit analyses show that the replacement of the traditional production systems of the Niger Inland Delta is not automatically justified by economic criteria. It can be seen that there is almost no profit margin and that the economic success of this new production system is very vulnerable to calamities in the field of management and world market fluctuations.

Alternative options

Bearing this in mind, and using more realistic costs of large-scale hydro-agricultural development and taking into account environmental risks, alternative options should be considered which may perhaps serve the aim of self reliance in food supply in a more secure and less harmful way.

Table 4: Integrating a floodplain's multifunctionality and its self regulation capacity in the
the Cost-Benefit Analysis
Traditional CBA for Office du Niger Project

	Yearly production figures of floodplain agriculture (pre-project situation)	Yearly production figures of irrigation project (project situation)
Surface under rice (ha)	112 000	40 000
Total paddy yield (t)	78 400	100 000
Unit yield (t ha ⁻¹)	0.70	2.5
Unit value (FM ha ⁻¹)	78 400	280 000
Inputs (FM ha ⁻¹)		
fertilizer	-	30 000
oxes, ploughs, etc.	-	13 200
management (rent paid to Office)	-	44 000
Margin of profit (FM ha ⁻¹)	78 400	192 800

Proposed Integrated CBA for Office du Niger Project based on water use

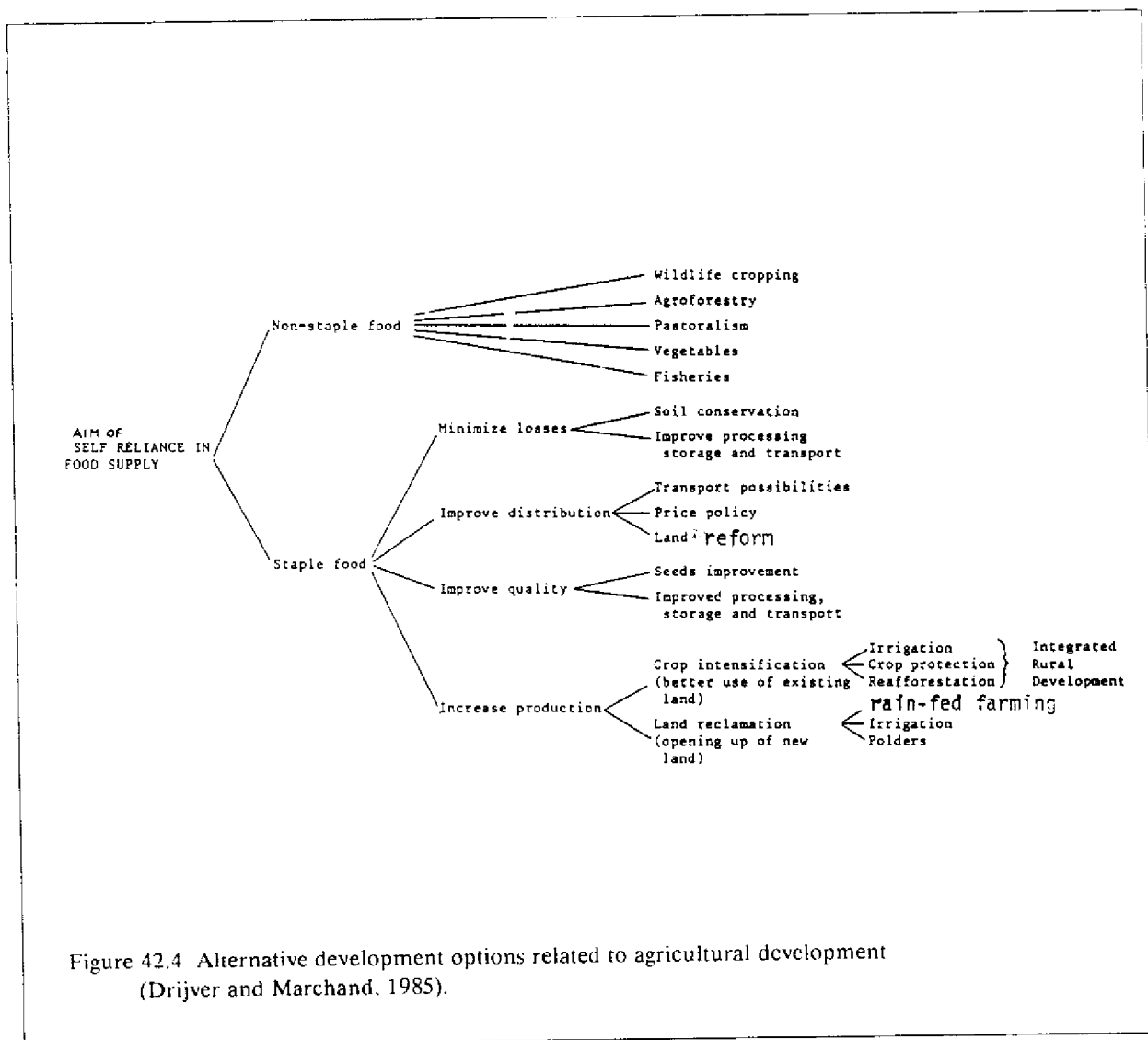
	Niger Inner Delta				Office du Niger		Total
	Meat	Milk	Fish	Rice	Total	Rice	
Total weight (t)	10 372	118 454	100 000	78 400		100 000	
Weight/100 (g)	44	506	426	235		5 003	
Value/100 (FM)	18	202	171	26	417	550	550
Protein yield/100 (g)	8	17	.77	18	119	190	
Energy yield/100 (Kcal)	83	318	401	853	1 656	13 749	
Inputs/100 m ³							
fertilizer	0	0	0	0		11	
management services	0	0		very small		84	
oxes, ploughs, etc.	0	0		very small		25	
Margin of profit/100 m ³					417 FM		430 FM
Loss of interest/100 m ³					0		1 084 FM
Net margin of profit/100 m ³					417 FM		654 FM

Assumptions: 1kg fish = 1kg meat = 1kg milk:1kg rice (paddy) = 110 FM:1kg fertilizer = 235FM
 construction costs of 1 irrigated ha = US\$ 8 000 = 6 800 000 FM
 loss of interest percentage per year = 8%
 management etc. of Office du Niger = rent paid by farmer = 44 000 FM/ha
 depreciation of farm tools etc. = 13 200 FM/ha

Note: 1 FM = US\$0.001

The sugar production is not included in this comparison (both in terms of water use and in yields).

The many possible alternative options that can be considered at national level are outlined in fig. 4. Before choosing one or a combination of these options, the development objectives should be defined more precisely.



Priority for local people

If the prospects and well-being of the local rural population are the major development objective than it is recommended that large scale dam-induced water regulation is avoided.

The most urgent bottleneck in traditional land use on non-regulated floodplains is the extreme low production level during dry years when practically no flooding occurs. Low crop and fish yields leading to human suffering are the direct result, while over-exploitation, especially during these critical years cause grave degradation of forests and grasslands.

Improvement of food *storage and processing* improve the nutritional situation both quantitatively and qualitatively during droughts. *Small-scale irrigation* which is developed as a step-by-step process and initiated and managed by the village population itself can be of substantial relevance. This village irrigation must be regarded as complementary to the existing flood recession and rainfed agriculture, that is with no intention of replacing those systems. The development of modest, small-scale village irrigation of, for instance, 10- 30 ha per village, implemented with floating pumps located in a nearby river or pond, can guarantee local food supply during droughts when the flood recession crops fall short.

The ecological integration capacity of these small projects is high. Their limited physical dimension often enables an optimal location to be found near the village, thereby avoiding conflicts with cattle raising and flood recession agriculture. In addition, their impact on the hydrological regime is usually insignificant, because streambeds remain intact.

Conservation of nature and natural resources

The balance between natural resources and traditional human activities in many floodplains is being disturbed more and more, due to a series of dry years from 1972 onwards and the high population growth rates of the last decades. These facts too call for intervention in order to prevent a serious deterioration of the basic living conditions in these regions.

On almost every floodplain studied, a large-scale degradation of natural forests is found. Therefore, priority must be given to coherent programmes of reforestation, rational forest management, energy saving methods and development of alternative energy sources.

In order to conserve the fish production potential in the long term it is necessary to identify the most important fish reproduction areas and to protect them against detrimental development. In addition, application of minimal mesh sizes is essential to prevent capture of juvenile fish which would seriously endanger the yields of future years.

Finally, action required to preserve valuable natural areas will be discussed here. Only three out of the seven floodplains have a national park, with a total protected area of about 200 000 ha. National parks are essential in that they ensure the conservation of the original flora, fauna and ecological processes on at least part of the floodplain. The future of the wildlife on the Logone and Kafue floodplains, for instance, is completely dependent on the protection given by the 'Waza' and 'Lochinvar' National Parks, respectively.

Combining the strengthening of traditional land use and conservation of nature and natural resources with a limited transformation towards modern agriculture

In some cases a part of the floodplain has already been converted into irrigated land. The coexistence of traditional and modern production may only be attained if the floodplain ecosystem as a whole remains intact. This implies that the modern irrigation projects must be restricted to a relatively small area of the floodplain (less than 10 percent) that they must have a small water demand, and that the modern irrigation projects have a major environmental component. Without such a component severe over-exploitation of grasslands, fishstocks and forests will result from the loss of traditional land together with the concentration of immigrants in and around the project.

At present this scenario can be encountered on the floodplain of the Logone in North Cameroon. Together with national counterpart institutes, the Centre for Environmental

Studies is executing an interdisciplinary field project. The project aims at the integration of traditional land use and nature conservation in and around Waza National Park, according to the principles of Unesco's Man and the Biosphere Programme. Both wildlife and local people in the project area suffer from the impacts of a large scale irrigation scheme in the vicinity. The mitigation of these impacts and the local capacity to adapt the use and management of natural resources to the new situation is of utmost importance.

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PAPER 43

RESULTS OF THE UNECE TASK FORCE ON THE APPLICATION OF ENVIRONMENTAL IMPACT ASSESSMENTS

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At their eleventh session (February, 1983) the Senior Advisers to ECE Governments on Environmental Problems decided to undertake a project on the *Application of Environmental Impact Assessment (EIA)* for specific types of activities. This project was carried out by a *task force* with the Netherlands as lead country. For two years the task force worked with the active participation of Canada, the Federal Republic of Germany, Finland, the Netherlands, Norway, Portugal and the USA. Other ECE member countries expressed their interest in the work of the task force, particularly Czechoslovakia, France, Hungary, Switzerland and the USSR.

The purpose of the work was to analyse practical experience with the application of EIA and to draw lessons from that experience. To that end, eleven case studies were carried out and analysed: six highway and five dam cases. In order to get a proper understanding of the case study material, information on the various national legal and administrative EIA systems was also gathered.

The case study information collected by the task force shows how, in eleven individual cases (highways and dams), environmental aspects were taken into account in the decision-making process. The individual projects that were studied varied considerably in terms of their size, technical and geographical characteristics and environmental impacts. Some cases represent examples of the application of EIA following certain formalized requirements whereas in other cases environmental studies were performed on an *ad hoc* basis.

Despite these differences, a basic assumption of the task force participants was that there are certain basic similarities or key elements which are responsible for a successful EIA wherever it is carried out and that a comparative case study analysis could help in identifying those elements.

A number of conclusions and recommendations related to EIA were formulated. The conclusions and recommendations are meant to be broadly applicable (i.e. to a wide variety of project types, not only highways and dams). They are meant to be of use to countries that already have a system of EIA and to countries interested in establishing an EIA system, including developing countries.

In the opinion of the task force participants, EIA consists not only of the writing of a report through which information is provided to the decision-maker, but also of procedural elements to make sure that the decision-maker takes the information adequately and fully into consideration. This is reflected in the general overall recommendation formulated by the task force which states that: "EIA should be viewed as an integral part of the project planning process beginning with an early identification of project alternatives and the potentially significant environmental impacts associated with them and continuing through the planning cycle to include an external review of the assessment document and involvement of the public".

The specific conclusions and recommendations of the task force have been divided into three categories:

1. Conclusions and recommendations related to the EIA process.
2. Conclusions and recommendations related to the content aspects of EIA.
3. Conclusions and recommendations regarding the link between the EIA and the decision.

The *process* aspects of EIA refer to a variety of activities aimed at ensuring the inclusion of environmental considerations in project planning. The case study material showed that it is not possible nor desirable to recommend a uniform approach. EIA is a decision-making tool dependent on the decision-making culture in a specific country. It varies greatly in the ECE region. However, certain process elements could be identified as being responsible for a successful application of EIA.

Broadly speaking those are the elements in the EIA process that guarantee that the decision-maker is provided with the right information and that this information is properly taken into account in the decision-making process.

For example:

- Scoping (i.e. identifying the significant alternatives and impacts for consideration in the EIA) involving the proponent, affected agencies and concerned publics;
- Outside review as a quality check of the information to be presented to the decision-maker;
- Public participation, and
- Monitoring.

These elements, among others, were identified by the task force as being responsible for a successful EIA.

Furthermore, the case study material revealed that in those cases where *formalized* procedural arrangements existed, including the steps to be carried out by those involved, the result was a valuable example of transparent planning and decision-making. In those cases different groups of participants were involved from an early stage, alternatives were taken into account and, in the end, a decision was taken that was socially and environmentally acceptable.

As far as the *content* aspects were concerned, it became clear from the case study analysis that there is little evidence that formalized methods were broadly used for predicting

impacts and/or comparing alternatives. In most cases *best professional judgement* and *previous experience* were the most commonly used methods for predicting impacts. Therefore, the task force recommended that in those cases where best professional judgements and previous experience were the main methods for prediction, the underlying assumptions and judgements be made clear.

The task force recommended that an Environmental Impact Statement (EIS) or other environmental documentation contain, at a minimum, the following content elements:

- Project setting (purpose and need);
- A description of the proposed project;
- A description of the existing environment;
- Reasonable alternatives including the do-nothing alternative;
- An assessment of the environmental impacts of the proposed project and the alternatives;
- Summary.

The task force also recommended that the EIS, or other environmental document, assess at a minimum, the direct and indirect impacts of the proposed project and the alternatives on the bio-physical and socio-economic environment. The specific types and number of impacts to be assessed are dependent on the individual project and the environment and can best be determined through scoping.

Concerning the *link between EIA and the decision*, it became clear from the case study analysis that only in those cases where some formalized EIA requirement existed, was there clear evidence that the EIA indeed played a role in the choice of the alternative as well as in design changes and mitigation measures. In the other cases the link between the environmental information and the decision was not discernable. The task force therefore recommended that any EIA process contain a mechanism for ensuring that its findings are adequately taken into account in the decision-making process.

The above summarised conclusions and recommendations of the ECE task force were unanimously agreed upon by the task force participants at their fifth and final meeting (May, 1985). The task force material, including the case study information and analysis, information on the national legal and administrative EIA systems in the participating countries and the conclusions and recommendations was presented to the ECE group of Experts on EIA in January, 1986 and received the final approval of the ECE Senior Advisers on Environmental Problems in March, 1986.

The Final Report of the task force is available from the Environment and Human Settlements Division of the United Nations Economic Commission for Europe (UNECE) in Geneva, Switzerland.

THEME V

**PUBLIC INFORMATION AND PARTICIPATION IN THE DECISION-MAKING PROCESS
IN RELATION TO LARGE WATER PROJECTS**

PAPER 44

PARTICIPATION PUBLIQUE A LA PLANIFICATION ET A LA GESTION DES RESSOURCES EN EAU: CAS DES GRANDS PROJETS HYDRAULIQUES

Didier Olivry⁴²

Resumé

Cette recherche porte sur l'étude des possibilités démocratiques d'une meilleure prise en considération des intérêts et des valeurs du public, et des préoccupations d'environnement dans les choix d'aménagement, et plus précisément, dans l'élaboration et la mise en oeuvre des grands ouvrages hydrauliques.

L'étude présente tout d'abord certaines caractéristiques du milieu aquatique et des équipements hydrauliques dans l'optique d'une meilleure association des acteurs à la gestion de l'eau, avant d'entreprendre une réflexion globale sur les problèmes généraux de la participation. Elle s'efforce ensuite de préciser par l'analyse de plusieurs études de cas, les principaux problèmes de participation afférents aux grands projets hydrauliques. L'étude dresse alors une analyse critique des outils usuels de participation du public, ainsi que des processus décisionnels et opérationnels entrepris à tous les niveaux. Enfin, plusieurs recommandations, portant notamment sur l'information, la négociation et les conflits, la prise de décision, et l'articulation des niveaux territoriaux, sont avancées pour aller dans le sens d'une mobilisation dynamique et d'une valorisation harmonieuse des potentialités sociologiques, économiques et écologiques.

Introduction

Aujourd'hui, en France, la participation est presque devenue de rigueur, et un grand nombre de personnes s'accordent sur la nécessité de son application. Ce large consensus est facilité, en partie, par l'extrême ambiguïté de la notion de participation et la grande diversité des situations qu'elle recouvre. Les expériences participatives autorisent, en effet, des pratiques sociales qui vont d'un simple changement dans la manière dont sont prises les décisions à une transformation radicale des rapports de pouvoirs au sein de la société. La question fondamentale n'est donc plus de savoir si la participation est nécessaire ou non, mais bien de déterminer quel type de participation mettre en oeuvre, à quel degré, à quel niveau et comment?

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L'émergence de ce mode, plus direct, d'intervention du public dans la prise de décision sur les grands choix qui le concerne, s'est surtout manifestée dans le domaine de l'aménagement. Les modifications dans l'utilisation du territoire, et les transformations apportées à l'environnement général sont, en effet, des ferments de mobilisation sociale. Il est ainsi apparu que le problème de participation du public se posait spécifiquement, et avec beaucoup d'acuité lors de l'implantation de grands projets hydrauliques. Ce sont des aménagements importants qui bouleversent la structure des espaces et des milieux, et qui imposent généralement de nouvelles règles de fonctionnement aux communautés locales. Ils traduisent également un certain style de développement fréquemment défini à un niveau territorial supérieur pour des bénéficiaires extérieurs et imposé au niveau local par le biais de choix technologiques. Ces aménagements affectent donc individuellement et collectivement un certain nombre d'acteurs, et sont d'autant plus mobilisateurs que la ressource en eau est en interface permanent entre les domaines technique, écologique et socio-économique.

Cependant, il a prévalu très longtemps, en France, une rationalité d'aménagement limitée principalement aux aspects techniques et économiques les plus évidents. Elle était surtout inspirée d'une intervention d'ordre quantitatif sur la ressource en eau sans trop se préoccuper des conséquences sur le milieu, sur le cadre de vie ou sur les équilibres socio-économiques locaux.

Ce modèle d'aménagement unifonctionnel a pu bénéficier pendant un certain temps d'une abondance qualitative et quantitative de la ressource en eau et d'une relative passivité des usagers.

Depuis, de nouveaux besoins et de nouvelles demandes plus qualitatives sont apparues (agriculture, industrie, établissements publics, collectivités locales, tourisme, loisirs,...), avec leur lot de problèmes à régler (pollutions, fluctuations temporelles et spatiales de la ressource, urbanisation, aménagement des bassins hydrographiques....). Dans le même temps, le nombre de personnes préoccupées de leur environnement, de la qualité de leur vie et de celle de leurs descendants est allé croissant.

Face à cette évolution de la demande et à l'arrivée de nouveaux partenaires, l'Etat a dû intervenir de manière plus directe dans le système de gestion de l'eau. Cela s'est traduit notamment par la mise en oeuvre d'une réglementation spécifique et par la création d'unités géographiques adaptées: les comités et agences de bassin. Ces moyens d'intervention ont montré leur efficacité à prévenir les grands déséquilibres quantitatifs et qualitatifs de la ressource en eau mais ils n'ont pas suffi à restaurer la responsabilité individuelle de la gestion de l'eau.

Ainsi, la résolution des problèmes de gestion des eaux demeure encore trop parcellisée et sectorielle. Cela provoque des situations conflictuelles entre des acteurs défendant seulement certains aspects particuliers des divers fonctions et usages de l'eau, ignorant ou négligeant souvent les besoins et les contraintes des autres partenaires.

Le problème majeur d'une politique de participation dans le domaine de l'eau sera donc de trouver un équilibre dynamique entre une exigence, celle d'associer les principaux usagers à la gestion et à la planification de leur ressource, et une contrainte, celle de maintenir une politique globale cohérente et harmonieuse des actions.

Cette présente recherche pose comme hypothèse qu'une pratique participative bien menée et associant réellement les usagers aux étapes essentielles du processus de décision en matière d'aménagement des eaux peut conduire notamment à:

- une gestion des eaux plus souple, adaptée aux usagers, à l'espace et au milieu,
- une répartition plus équitable des ressources et des moyens,
- une meilleure intégration des actions d'aménagement au niveau local,
- une responsabilisation des acteurs par une prise de conscience des divers fonctions et usages de l'eau et de la légitimité des besoins des autres acteurs,
- une valorisation patrimoniale des ressources naturelles et de l'environnement.

Partant de ces notions essentielles, indiquant que la participation est utile aux instances de décision, conforme à certains principes écologiques et sociaux et nécessaire à la bonne réalisation des aménagements, la recherche s'est efforcée de détecter par l'analyse de nombreuses études de cas des moyens concrets susceptibles de favoriser une meilleure prise en compte des intérêts et des valeurs des usagers dans la définition et la mise en oeuvre des projets hydrauliques.

Les études de cas ont porté principalement sur de grands projets hydrauliques publics et collectifs, répartis sur tout le territoire français (notamment les barrages-réservoirs "Seine", "Aube", de Naussac, de Saint-Croix-sur-Verdon, de Villerest, du Drennec et d'Arzal; les projets envisagés de Saint-Geniez-d'Olt, de Lémézec, d'Origny-Sainte-Benoîte et de Villers-le-sec; le projet d'irrigation de la vallée du Calavon et sud-Lubéron, le schéma d'aménagement des eaux du bassin de la Sèvre Nantaise, le contrat de rivière sur le Trieux et l'aménagement agricole des marais breton et poitevin). La description et l'analyse des processus institutionnel, décisionnel et instrumental de la participation se sont également inspirées de nombreux autres grands projets (énergétiques, industriels et de transports). Enfin, l'analyse d'expériences étrangères et notamment celle des enquêtes publiques sur des projets hydrauliques en Angleterre ont permis d'apporter des éléments de comparaison et d'enrichir la réflexion dans un contexte institutionnel et social différent.

1. Réflexions générales sur la participation

Avant d'exposer certains points importants de la recherche, il est nécessaire de clarifier les termes du sujet et de définir les modalités et les niveaux d'intervention du public.

La participation peut se définir comme l'ensemble des possibilités démocratiques offertes à la population de collaborer à la prise de décision. Mais une participation authentique et dynamique implique un engagement actif des citoyens dans la résolution de problèmes qu'ils jugent essentiels et pertinents et dont ils peuvent effectivement concourir à élaborer et à contrôler les solutions.

Il est bien sûr d'autres définitions tant à caractère général que sectoriel, mais il importe surtout de retenir quatre traits essentiels de la participation en matière d'aménagement:

- les divers types et niveaux d'intervention possibles du public au cours du temps, selon les projets ou selon les lieux,
- le caractère public de la participation qui permet de dépasser certains cadres personnels pour s'impliquer dans une action collective,

- la présence indispensable d'un enjeu, d'un thème mobilisateur autour duquel et pour lequel certains acteurs jugeront bon de s'investir et au besoin même affronter certains pouvoirs,

- enfin, la participation exige la présence d'une certaine marge de manoeuvre, c'est-à-dire d'une possibilité réelle d'agir et d'infléchir les décisions.

Le cadre de la participation ainsi présenté demeure cependant suffisamment ouvert pour autoriser de nombreuses utilisations et interprétations. Il est en effet possible de distinguer plusieurs degrés de participation suivant le niveau d'engagement des citoyens dans un processus (voir tableau ci-joint).

Ces divers éléments de classification et de typologie permettent de définir et de cerner d'un peu plus près la notion de participation. Il convient cependant d'être conscient de la difficulté d'établir une hiérarchie entre les nombreuses formes de participation. Ainsi, dans la pratique, la participation apparaît le plus souvent comme un phénomène global, complexe et évolutif, passant par plusieurs stades et/ou intégrant plusieurs niveaux.

Cependant, si la participation peut être généralement considérée comme souhaitable, elle n'est pas une panacée, il faut donc se garder de considérer comme "bonnes" toutes les formes de participation. C'est ainsi qu'il paraît nécessaire de s'interroger sur la signification, les objectifs et les fonctions sociales de la participation dans un milieu donné et sur la disposition et les intentions des organisateurs comme des participants. Il semble donc important de connaître les limites de la participation: limites inhérentes au processus lui-même (disponibilité, inégalité d'accès à l'information, notabilisme, représentativité, contradictions, divisions,...) mais aussi imputables aux maîtres d'ouvrages et aux professionnels (défaut de méthodologie et de critères d'investigation, manipulations, leurres ou alibis, réticences,...). C'est cette entrave provenant des organisateurs de la participation que nous allons analyser au travers des études de cas.

2. Réflexions sur les études de cas

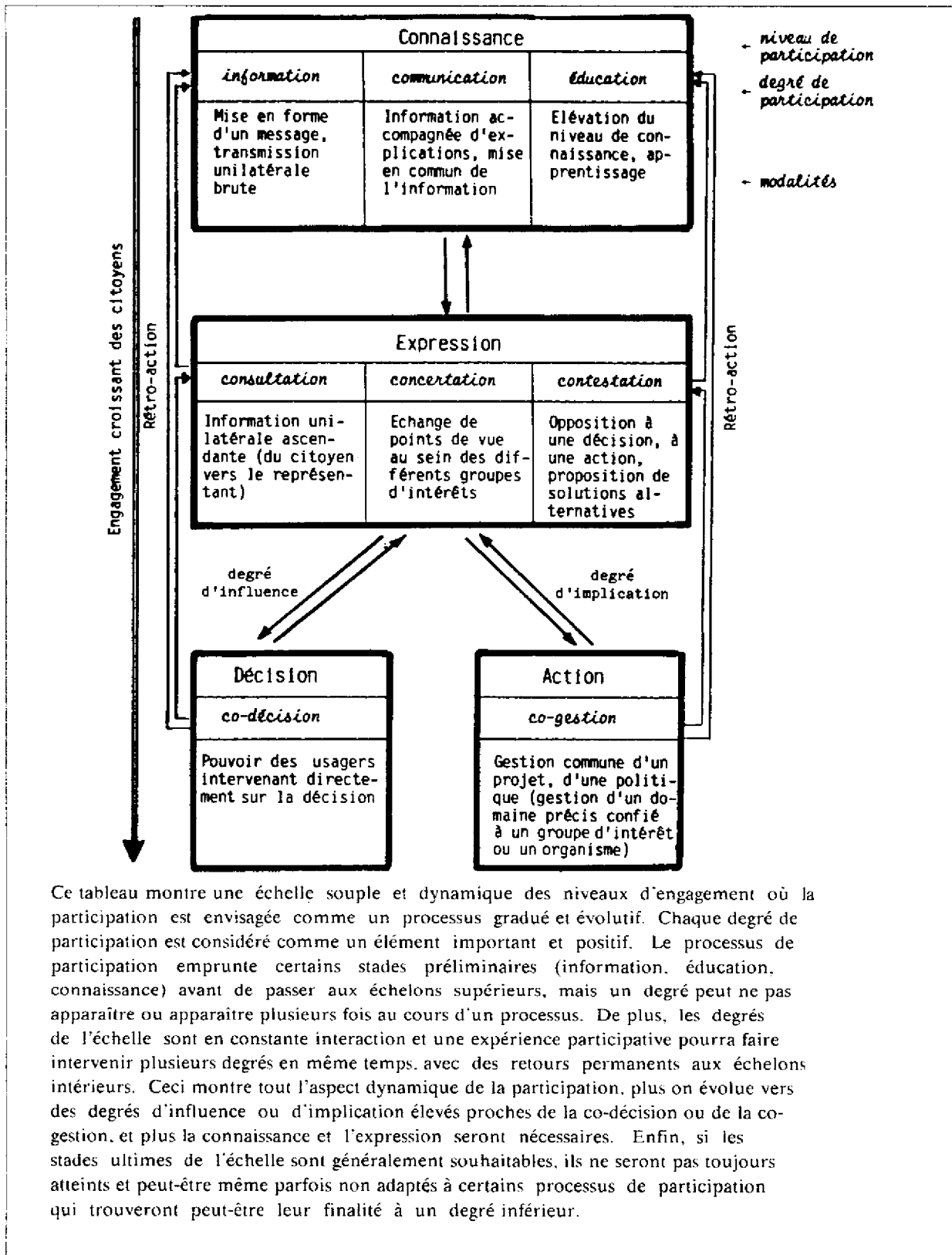
En prenant en considération les grands projets hydrauliques publics, c'est tout l'aspect de la planification et de la gestion de la ressource en eau et/ou de son utilisation qui est concerné. Cela va motiver l'intervention d'un grand nombre d'acteurs auprès du maître d'ouvrage dont notamment:

- les communautés locales, comprenant la majeure partie des usagers du territoire concerné (agriculteurs, industriels, collectivités locales, pêcheurs, randonneurs, etc.);

- les groupes d'intérêts, regroupant les principaux acteurs usagers de la ressource en eau ou de son utilisation (organismes professionnels, collectivités locales, fédérations de pêche, association de protection ou de défense,...);

- les institutions extérieures exerçant une influence sur le territoire concerné (administrations de l'Etat, établissements publics; institutions régionales et départementales,...);

- enfin, les médias jouant le rôle de relais d'informations et d'opinions entre ces différents partenaires.



Cependant, l'ensemble des études de cas analysées montre un contexte général de mise en oeuvre des projets hydrauliques, assez peu ouvert à l'intervention de ces nombreux acteurs. Les maîtres d'ouvrage s'inspirent plutôt d'une philosophie d'action établie sur un plan technique et conduisant à des interventions sectorielles sur la ressource en eau. Ils adoptent souvent une attitude très défensive, centrée sur la réalisation dans les meilleurs délais et au moindre coût de leurs objectifs. Cela se traduit par une fermeture du champ décisionnel et une politique du "fait accompli" et de la "fuite en avant" entretenue de plusieurs manières:

- une information partielle, orientée ou inadaptée,
- une négation des conflits et des divergences inhérents au projet, par un appel à des thèmes rassembleurs ayant pour volonté de dissimuler les diverses rationalités territoriales et sectorielles,
- un discours scientifique et technique se substituant à l'exercice d'un débat public et à un arbitrage politique,
- une tentative de normalisation du corps social selon des représentations et une vision restrictive, plutôt qu'une recherche du débat public sur les enjeux d'une politique de l'eau.

Il est vrai que face à la nature conflictuelle des nombreux usages de l'eau (conflits de valeurs, sectoriels ou territoriaux), les maîtres d'ouvrage se trouvent un peu démunis. Leurs formations les a souvent peu préparés aux débats sociaux et aux techniques de communication. Ils ont tendance alors à se réfugier derrière l'utilité publique globale ou la qualité technique de leur projet. Cela n'est pas sans provoquer quelques heurts avec un public "arc-bouté sur son terrain", sur ses revendications locales et qui conteste la logique du projet. Les études de terrain montrent alors que la participation conduit à un "dialogue de sourds" où les débats de pouvoir et de légitimité supplantent les débats de fond. Les effets dommageables d'une telle situation sont alors importants:

- mauvaise acceptation du projet et sous-utilisation de ses aménagements connexes,
- augmentation des coûts économiques, sociaux et d'environnement,
- conflits stériles et violents entre intérêts divergents et contradictoires,
- insatisfaction des besoins,
- difficile réappropriation locale des avantages du projet,
- climat peu favorable à la prise de conscience des problèmes liés à l'eau et à l'environnement général.

Il convient donc d'examiner certains points spécifiques qui contribuent à cet état de fait.

A) Multiplicité des intervenants et des conflits territoriaux

Un des premiers problèmes de la participation dans les projets hydrauliques est la multiplicité des acteurs intervenant à des niveaux territoriaux différents.

Le cas du projet de barrage-réservoir à Saint-Geniez-d'Olt dans l'Aveyron illustre assez bien cette question. La construction de ce barrage est envisagée en amont du bassin hydrographique du Lot qui connaît à l'heure actuelle un problème majeur qui est celui du déficit chronique de la ressource en eau. Le projet de stockage d'environ 50 Mm³ d'eau au droit de Saint-Geniez- d'Olt durant la période excédentaire vise donc à relever les débits d'étiage de la rivière, pour enrayer une partie de la pollution, approvisionner les agglomérations du bassin aval et surtout permettre le développement agricole de la basse vallée du Lot (irrigation dans les départements du Lot et du Lot-et- Garonne).

On retrouve ici un élément important qui caractérise fréquemment les projets hydrauliques où une recherche de rentabilité technique et économique a entraîné inévitablement une concentration et une spécialisation géographique: les coûts ou les risques d'un projet ne sont souvent plus supportés que par une fraction limitée de la population ou du territoire, alors que ses avantages sont au contraire largement diffusés. Il en résulte souvent une confrontation, ouverte ou occultée, entre la logique du maître d'ouvrage et celle de la population locale. L'aménagement, investi de la légitimité que lui confère l'intérêt général (combler le déficit en eau de la rivière) et soutenu par des intérêts puissants (agriculteurs et industriels du bassin aval), va très rapidement vouloir imposer sa rationalité technico-économique sur le territoire d'implantation de l'ouvrage. La participation sera alors d'autant plus difficile que la population locale se sentira alors dessaisie de son espace local, menacée dans ses valeurs et agressée dans son environnement.

A ce déséquilibre s'ajoute fréquemment, comme c'est le cas à Saint-Geniez-d'Olt, le fait que les régions d'implantation des ouvrages sont des régions rurales, peu peuplées et localisées dans des secteurs géographiques défavorisés.

Une autre question importante, qui découle directement de la précédente, est celle de la présence de nombreux intervenants aux intérêts et aux logiques souvent fort différents. C'est le cas ici du projet de Saint-Geniez-d'Olt qui réunit quatre régions-programmes, cinq départements, 590 communes ainsi que toutes les administrations et services intervenant dans le domaine de l'eau. Une telle situation est beaucoup plus favorable à la programmation d'un équipement pour laquelle un consensus entre toutes les parties peut s'élaborer et un programme de financement se monter qu'à une intégration et une amélioration de la gestion courante de l'eau.

Il est vrai que tout concourt actuellement à la programmation des gros équipements, les modes de financement favorisent les réalisations au détriment de l'amélioration du parc existant (incitations financières des Ministères aménageurs, fiscalité communale,...); l'activité politique préfère les inaugurations à la rénovation de la gestion quotidienne; le prestige et la technicité sont associés aux grands ouvrages avec la symbolique qui lie les honneurs aux grandes oeuvres. Enfin, la décentralisation qui en multipliant les partenaires diminue les chances de trouver un consensus sur l'aménagement des différentes demandes en eau et conduit à agir sur l'augmentation de la ressource.

B) Parcellisation des responsabilités, des décisions et des actions

Malgré les gros efforts de planification et de coordination au niveau national dans le domaine de l'eau, les études de cas montrent dans l'ensemble, une absence de perception globale et cohérente des projets d'aménagement. Les actions sont effectuées sans grande complémentarité, chacun intervenant sur sa portion de territoire ou selon sa fonction spécifique. C'est un peu ce qui s'est passé lors de la réalisation du barrage-réservoir "Seine" et de ses aménagements connexes.

Le barrage-réservoir "Seine" a été réalisé en vue d'assurer la protection contre les inondations et le soutien des débits d'étiage de la rivière en été. Cet ouvrage, construit en dérivation de la Seine, se situe à l'Est de Troyes (Aube) dans la région de la Champagne humide. Il a été déclaré d'utilité publique le 25 septembre 1959 et mis en eau le 27 janvier 1966 après 5 années de travaux et peut contenir 205 Mm³.

Le maître d'ouvrage du barrage-réservoir était le département de la Seine, qui assura, avec l'aide de l'Etat, la totalité du financement du projet. Le Conseil Général de l'Aube, quant à lui, décidait, par délibération du 12 janvier 1954, de ne pas se prononcer pour ou contre le projet et s'opposait à toute participation financière du département.

L'examen rapide des différentes phases de la procédure préalable à la réalisation de l'ouvrage et de ses aménagements montre une absence de cohérence qui aura des répercussions sur la perception et l'acceptation du projet par la population locale:

- 25 septembre 1959: les travaux de construction du barrage-réservoir "Seine" sont déclarés d'utilité publique par décret ministériel;

- 26 mai 1964: convention passée entre les départements de l'Aube et de la Seine relative à l'aménagement touristique et sportif et l'exploitation de la pêche et de la chasse au gibier d'eau;

- 27 janvier 1966: mise en eau du barrage-réservoir "Seine";

- 26 avril 1966: la Préfecture de Région Champagne-Ardenne engage une étude sur les possibilités d'aménager le plan d'eau et ses abords;

- 16 octobre 1970: création du parc naturel régional de la forêt d'Orient.

Cette brève énumération de dates montre que le département de la Seine (maître d'ouvrage) commence la réalisation du barrage-réservoir bien avant la convention passée avec le département de l'Aube. Il limite donc explicitement sa compétence à l'ouvrage lui-même et à son exploitation principale. Il ne sera donc pas possible de remanier la conception ou la gestion du réservoir en fonction des utilisations annexes du plan d'eau. D'ailleurs, l'étude sur les possibilités d'aménagement du site et de ses abords intervient plus de 6 ans après le début des travaux.

D'autre part, le maître d'ouvrage envisage, dans la convention passée avec le département de l'Aube (26 mai 1964), la concession de l'utilisation du plan d'eau à des fins touristiques et sportives, comme une mesure compensatoire globale palliant les inconvénients de la réalisation de l'ouvrage. Or, cette compensation générale sous forme de concession gratuite des aménagements annexes, évite un recensement des inconvénients de l'ouvrage au niveau de chaque acteur. Elle ne permet donc pas de savoir si tous les préjudices résiduels seront réellement couverts par cette mesure, ni quelles sont les personnes qui en bénéficieront.

Enfin, il ne faut pas négliger l'impact psycho-sociologique important qui se traduira notamment par un refus d'utilisation du site et de ses abords par les bâtiments. En effet, cette parcellisation territoriale et fonctionnelle s'est traduite par une série d'expropriations successives mal ressenties par la population.

Dans cet exemple, il est manifeste qu'un plan d'ensemble d'aménagement de la zone et une association de la population à la réalisation de l'ouvrage auraient permis une valorisation des effets positifs de celui-ci et une meilleure acceptation locale du projet. Ce problème s'est d'ailleurs rencontré de façon similaire pour les projets du barrage de Sainte-Croix-du-Verdon et de Naussac sur l'Allier.

C) Refus du débat social et arbitraire technique

Le processus de décision en matière d'aménagement hydraulique tend fréquemment à occulter le conflit ou à le reléguer à une place secondaire. Il est envisagé comme un dysfonctionnement, une aberration temporaire dans un système qui, somme toute, demeure satisfaisant. Les études ont montré que la négation du conflit passe très souvent par une démission des instances politiques et par une référence à la rationalité technique, garant de la cohérence interne du projet.

Si toutefois certaines oppositions apparaissent, elles sont corrigées et compensées par des actions de propagande, de persuasion sociale ou d'indemnisation financière.

Dans cette optique, la participation ne porte pas sur les logiques socio-économiques et politiques qui sous-tendent le projet, mais seulement sur des aménagements de détail. Elle naît d'une volonté aplanissante et se base sur la ferme conviction du bien fondé des actions engagées.

Cette question est illustrée par le cas du barrage-réservoir "Aube", situé sur l'Aube (affluent de la Seine). Les objectifs affichés de cet ouvrage sont le soutien d'étiage des rivières de l'Aube puis de la Seine, la protection du bassin aval contre les crues et l'approvisionnement en eau de la région parisienne.

Or, ce projet entraîne la submersion de 2 500 ha de terre, dont plus de 1 200 ha de terres agricoles, si bien que dès le départ, la profession agricole s'est fortement mobilisée pour infléchir les objectifs du projet en sa faveur. L'idée principale défendue était de faire compenser par les usagers situés sur le cours aval de la rivière, qui trouveront une eau de qualité et en quantité suffisante, les préjudices subis. Les agriculteurs se sont alors groupés auprès de leur syndicat pour entamer un processus de négociation avec le maître d'ouvrage.

Le résultat de cette "participation" est l'octroi par le maître d'ouvrage d'un certain nombre de mesures d'accompagnement dont voici les principales:

- restructuration foncière (remembrement) étendu à 10 communes et financée à 100 pourcent par le maître d'ouvrage;

- travaux connexes au remembrement (voirie, hydraulique) pris également en charge par le maître d'ouvrage;

- drainage de 3 400 ha de terres agricoles financé à 30 pourcent par le maître d'ouvrage et subventionné par l'Etat;

- participation financière du maître d'ouvrage aux aménagements agricoles du lit mineur de la rivière (protection d'environ 14 000 ha de terres contre les crues décennales);

- aide aux agriculteurs pour le passage d'un mode de culture extensif à un mode de culture intensif;

- recalibrage des cours d'eau du bassin de l'Aube et de la Seine, financé à 80 pourcent par le maître d'ouvrage;

- reconstitution forestière équivalente en priorité dans le département de l'Aube, par aménagement de friches à reboiser ou de forêts dégradées qui seront soumises au régime forestier (action régulatrice des surfaces boisées).

Si dans ce type de participation les principaux acteurs semblent satisfaits, il convient tout de même d'apporter quelques critiques au procédé:

- tout d'abord, ce genre de discussion avec une partie de la population peut aboutir, si on n'y prend garde, à des concessions anarchiques au détriment de l'utilité de l'ouvrage et de l'analyse des répercussions du projet sur d'autres acteurs ou sur d'autres domaines (il est parfois utile d'envisager d'autres variantes);

- il ne faut pas perdre de vue non plus le coût d'une telle démarche. C'est ainsi que, suite à l'étude du barrage Aube, l'Agence Financière de Bassin Seine -Normandie a recherché des possibilités de fixer les modalités et les limites des mesures compensatoires;

- d'autre part, la négociation a tendance à favoriser les groupes structurés et les intérêts prédominants. Il convient de faire attention à ce qu'un certain "marchandage" ne s'installe pas. Cela reviendrait à offrir aux populations concernées une contrepartie suffisante qui permette de faire accepter le projet;

- enfin, une utilisation abusive des mesures compensatoires peut aussi conduire à des effets néfastes pour l'environnement. On peut ainsi justifier n'importe quel projet, même celui qui détruit le plus le milieu naturel, car il sera possible de compenser ailleurs ou autrement. On pourrait ainsi, en poussant un peu trop loin le raisonnement, compenser des dommages directs à l'environnement par des avantages économiques concédés à des groupes d'intérêts.

D) Utilisation ponctuelle et limitée des techniques de participation

L'étude de plusieurs projets hydrauliques a permis d'identifier un grand nombre d'outils de participation (études d'impact, enquête publique, audition publique, référendum, organismes consultatifs, médiation,...). Ces instruments sont initialement conçus pour permettre une meilleure association du public aux décisions d'aménagement, cependant, dans la majeure partie des expériences de participation, le maître d'ouvrage utilise un instrument donné comme un moyen privilégié de participation. Ainsi, le récent engouement pour les référendums et les auditions publiques a parfois conduit à centrer toute la procédure sur l'emploi d'un de ces outils. Il arrive alors très souvent qu'il encourage la confrontation et envenime les conflits. La déception sera dans ce cas à la mesure des attentes, car le moyen utilisé ne s'inscrit pas dans un programme de participation; l'outil coupé de son contexte, sera "mal employé" et le moment choisi sera inopportun.

Cette question est illustrée par le cas du projet de Saint-Geniez-d'Olt évoqué précédemment et où deux auditions publiques successives ont eu lieu.

L'audition publique est une procédure d'information mutuelle non obligatoire. La phase principale de l'audition dans le cas présent est la réunion publique qui fait suite à une exposition itinérante où les principaux aspects du projet sont présentés au public. La réunion publique a donc pour but de répondre aux nombreuses questions posées par écrit et

par oral durant l'exposition et aux observations mentionnées sur les questionnaires en circulation.

La première réunion publique réunissait dans une grande salle de Saint-Geniez- d'Olt une assistance composée d'environ 600 personnes dont l'immense majorité provenait des communes concernées directement par le projet. A la tribune face au public, il y avait le représentant du maître d'ouvrage, deux représentants d'EDF, un représentant de l'Agence financière de Bassin et un représentant de chaque service technique départemental ou régional.

En effet, d'une manière générale, les questions abordées par l'assistance renvoyaient à un débat global sur la politique de l'eau dans le bassin, les orientations économiques de la région, l'avenir du pays, etc. Or, les personnes présentes à la tribune étaient essentiellement des responsables techniques. Cela n'a pas été sans instaurer une relative ambiguïté dans le débat; la tribune présentait une solution technique fondée sur des bases que l'assistance contestait sur le plan politique et social. Un processus de participation avait été engagé sans aucun accord préalable sur les règles du jeu.

L'absence de consensus sur la problématique de départ et sur les règles du jeu va bien sûr conduire à un débat stéril et conflictuel. L'audition publique s'est finalement caractérisée par l'opposition de deux systèmes de valeur bien distincts:

- d'un côté, des techniciens soutenant un projet précis, bien étudié et sans alternative dont l'objectif principal est la résolution du problème d'aménagement des eaux et les contraintes majeures, les problèmes socio- économiques et écologiques;

- de l'autre côté, une population placée devant le fait accompli, contestant le raisonnement technique et le bien-fondé des besoins exprimés.

C'est sans doute ce constat qui a conduit le maître d'ouvrage à envisager une deuxième audition publique en proposant cette fois d'autres intervenants.

Lors de cette deuxième audition, étaient présents à la tribune les présidents et représentants des conseils généraux des départements concernés. Dans la salle, le public se composait de 600 à 700 personnes, assistées de leurs élus.

Cette fois, la présence à la tribune d'élus politiques de tout le bassin du Lot va permettre de lever un peu l'ambiguïté "politique-technique" en restituant au débat politique le choix des orientations confié aux techniciens. Les règles du jeu sont modifiées, les élus sont habilités à discuter de la réalité des besoins. Un authentique débat politique sur le choix des objectifs peut s'engager. La présence de représentants des populations situées en aval sur la rivière permet, à ce titre, à la population locale d'identifier les bénéficiaires potentiels et de juger de la légitimité des besoins exprimés et de la pluralité des intérêts en jeu.

Cette seconde audition publique se démarque de la première par un débat plus constructif et une opposition beaucoup moins unanime et tranchée. Elle montre bien que les voies par lesquelles on agit sont au moins aussi importantes que les finalités même de la participation.

E) Bilan des études de cas

En faisant un retour en arrière sur les études de cas, on constate que les expériences de participation sont très souvent occultes, parcellaires, voire irraisonnées. Le public, tant les individus que les groupes, se trouvent engagé dans un processus assez peu maîtrisé et mal défini. Il est difficile de déterminer un objectif général ou des idées directrices totalisantes sur la place, le rôle et les buts assignés à la participation.

Ainsi, outre certaines "perversions" de la participation, qu'il est toujours possible de rencontrer (manipulation, démagogie, marchandage, récupération, détournement d'intentions, etc.), les processus de participation examinés dans les études de cas restent souvent insatisfaisants pour les acteurs directement impliqués, et ce, pour plusieurs raisons:

- la procédure de participation intervient trop en aval de la décision, lorsque les choix sont en partie opérés,
- les outils de participation sont souvent inadaptés ou alors employés à mauvais escient,
- le niveau territorial de participation reste souvent très mal défini,
- les maîtres d'ouvrage ne sont pas préparés à mener un processus de participation, ni surtout à affronter une certaine contestation,
- il demeure toujours une inégalité flagrante dans les débats entre les promoteurs du projet qui connaissent bien les dossiers et maîtrisent la procédure, et le public, qui réagit viscéralement avec sa sensibilité et sa connaissance des lieux. L'information est souvent tardive, unilatérale ou incomplète,
- le public concerné, sans règle du jeu précise, ne sait rarement à quoi il s'engage et ce sur quoi on lui demande de participer. Il doute fréquemment de l'honnêteté des partenaires et de ses chances à se faire entendre.

Il en résulte de nombreuses frustrations, des antagonismes et des malentendus. Le public ne sait pas trop à quoi il s'engage et se fait souvent des illusions sur son degré de liberté ou sur son pouvoir réel. Son intervention est alors plus revendicative qu'innovante, car il a souvent l'impression que la participation est une vaste "supercherie" ou un exercice purement formel qui fait miroiter un pouvoir qui, finalement lui échappe.

Il convient donc, tout d'abord, de lever une partie des ambiguïtés qui pèsent sur la notion de participation, c'est-à-dire de définir: l'objectif, le contenu et les formes que l'on entend lui donner. Pour cela, il est nécessaire d'élaborer au préalable un programme qui définisse les moyens engagés, les mécanismes employés et qui précise les modalités et les limites de l'intervention du public.

3. Vers une nouvelle stratégie de la participation

Il importe de bien se rendre compte qu'en matière de communication sociale, la simple motivation et la bonne foi des interlocuteurs ne suffisent pas à assurer une participation positive et fructueuse. Il demeure bien sûr une grande part d'impondérable qui tient autant à l'originalité de chaque projet qu'à la qualité des acteurs en présence. Aucune démarche systématique de participation et transposable pour tous les cas ne peut être préconisée. Cependant, la recherche a permis de dégager certains principes de base qui permettront d'éviter certains blocages potentiels et de se prémunir contre certaines difficultés logiques.

A) De l'utilisation des outils de participation

Au cours des dernières années, un certain nombre de réformes ont été entreprises pour intéresser, de manière plus affective, le public à la formulation et à la mise en oeuvre de décisions concernant son cadre de vie. C'est ainsi qu'un outil formel de participation du public à la prise de décision a été créé: l'étude d'impact. Instituée par la loi du 10 juillet 1976, relative à la protection de la nature, l'étude d'impact a pour objectifs ambitieux d'apprécier les conséquences sur l'environnement des projets importants comme les projets hydrauliques, d'informer l'ensemble des acteurs intéressés et de constituer un outil d'aide à la décision.

La portée de l'étude d'impact a été récemment renforcée par la réforme d'une autre procédure formelle: l'enquête publique. La loi du 12 juillet 1983, relative à la démocratisation des enquêtes publiques et à la protection de l'environnement et améliore les modalités d'enquête pour permettre une plus grande intervention du public.

Par ailleurs, d'autres procédures ont été créées ou développées pour assurer un plus large accès aux informations d'ordre technique et scientifique et fournir d'autres possibilités de participation des citoyens, ce sont essentiellement: les auditions publiques, le référendum, les organismes consultatifs, les organismes de médiation et les recours en justice.

L'ensemble de ce dispositif instrumental semble plutôt favorable à une meilleure association du public aux décisions d'aménagement. Cependant, comme tous les outils, ils peuvent être correctement ou mal utilisés.

Bien sûr, il n'existe pas dans l'absolu de bons moments pour participer, ni de bons outils de participation. Chaque instrument doit être conçu comme une étape dans un processus de participation au cours duquel le public a déjà eu d'autres possibilités d'expression. Les outils ne peuvent que valider ou sanctionner un programme de participation déjà entamé.

Il apparaît, au vu des études de cas et à l'analyse des principaux instruments et de leurs limites, qu'une meilleure efficacité des outils est obtenue par l'usage diversifié d'outils adaptés aux différents stades d'évolution des projets. Il est en outre souhaitable qu'ils soient employés de façon complémentaire pour assurer une participation continue tout au long du processus de décision.

Il est ainsi possible d'envisager une procédure largement ouverte où, par exemple, l'étude d'impact en cours d'élaboration constitue la base d'une discussion, l'audition publique garantit l'expression de chacun et valide le processus de participation. L'enquête publique peut alors sanctionner une démarche participative et le référendum trancher entre deux possibilités bien étudiées, complètes et contrastées. Quels que soient les outils retenus, il semble important que la dynamique de participation se structure progressivement pour présenter au cours des différentes étapes du processus de décision des règles de jeu de mieux en mieux définies.

Cependant, la participation ne peut se résoudre à un ensemble de techniques appropriées pour susciter et maintenir l'intervention des acteurs concernés. En effet, les outils ne sont pas indéfiniment perfectibles, et il faut être conscient de leurs limites; ainsi, ils ont tendance à figer l'intervention du public en lui donnant un caractère statique, or, le processus de décision en matière d'aménagement présente surtout un caractère dynamique. Les outils de participation se présentent aussi parfois comme des moyens de légitimer certaines décisions déjà opérées et permettent rarement la remise en cause fondamentale des solutions proposées.

B) La participation : un programme avec ses règles du jeu

L'ouverture de certaines étapes du processus de décision aux acteurs de la société civile n'est concevable que si les règles du jeu sont préalablement définies et acceptées. Il convient en effet de déterminer un programme qui permette l'expression des initiatives et des aspirations des usagers, mais aussi et surtout l'exercice d'un arbitrage entre les divers intérêts.

Une des principales ambiguïtés qui règnent autour de la mise en oeuvre d'un processus de participation réside dans le fait qu'il permet à certains groupes ou individus d'intervenir comme partenaires actifs dans le processus de décision, alors que cette intervention est fréquemment objet de conflits car source d'enjeux, de rapports de forces et de pouvoirs. A ce titre, l'eau est un domaine où la cohabitation et la concurrence pour l'utilisation d'une même ressource liée à l'occupation d'un espace est particulièrement source de conflits.

La participation devra donc, sinon tenter une réconciliation et une coopération entre acteurs, au moins trouver un terrain d'entente qui permette l'expression et la reconnaissance des acteurs et la formulation de leurs revendications.

En effet, pour qu'un processus de participation aboutisse à un choix collectif, il est nécessaire que tous les acteurs adhèrent à des règles communes qui structurent leur espace politique et social. Or, comme le disait Brecht, "le grand avantage du football sur le théâtre, c'est qu'au football, les spectateurs connaissent les règles du jeu". Il en est de même pour les opérations d'aménagement comme les projets hydrauliques: les acteurs veulent exprimer leurs connaissances de la ressource en eau, leurs préoccupations et leurs besoins, mais ils ignorent fréquemment l'art et la manière de le faire. La participation doit donc apporter une définition précise des règles du jeu, rechercher une adhésion et un large consensus sur ces règles du jeu et assurer le respect de celles-ci par l'ensemble des partenaires.

Cela suppose, bien entendu, que les maîtres d'ouvrages et les professionnels dépassent l'arbitraire social et les pouvoirs établis pour se replacer dans une analyse générale qui accepte les tensions inévitables et exerce un arbitrage équitable entre intérêts sociaux parfois opposés. A ce niveau, la participation est un véritable pari sur la capacité des institutions à organiser le débat, à favoriser la dynamique sociale et à gérer les conflits.

La participation pourra alors conduire à un consensus minimum entre les principaux acteurs autour d'une orientation générale. Néanmoins, ce nouveau "contrat social" ne pourra aboutir que si les niveaux décisionnels et les responsabilités sont clairement définis à chaque étape du processus de décision.

C) Vers un processus de décision ouvert et gradué

Les études ont montré que peu d'institutions, de structures ou d'activités visant à susciter la participation possèdent des concepts d'actions très clairs ou des idées précises sur ce qui se passera grâce à leur action. Ceci entretient une extrême confusion entre les niveaux de décision et maintient un amalgame de critères très variés à tous les stades du processus.

Dans une optique participative, il importe de se livrer à un travail d'éclaircissement et d'approfondissement des objectifs et des méthodes de travail, pour s'orienter vers une solution efficace, acceptable et cohérente. Pour cela, il est nécessaire d'établir une

procédure qui donne au public toute garantie dans ses phases successives, c'est-à-dire, qu'il pourra maîtriser et infléchir matériellement et intellectuellement. En effet, un pouvoir de proposition, de conception, de décision ou de contrôle, n'est réellement partageable que s'il est bien identifié, reconnu et réellement exercé. Il semble important notamment de lever la dualité politique-technique, par exemple, en responsabilisant les élus pour que certaines décisions issues du débat démocratique apparaissent légitimes en tant que telles. Pour cela, il est souvent nécessaire de distinguer un niveau politique général (celui des orientations générales et des grands choix), un niveau plus technique (celui de la définition des actions) et un niveau socio-économique (celui de la définition des modalités et des mesures d'insertion.)

1) Niveau politique

C'est un niveau de participation très large qui doit permettre aux citoyens d'être associés à la détermination des objectifs généraux avant que les débats ne s'engagent sur des projets spécifiques. Les principaux problèmes ne sont donc pas d'ordre technique, mais concernent des choix politiques sur la gestion des ressources et des milieux. Il s'agit d'arrêter des objectifs précis qui tiennent compte des données économiques, des attentes du public et de l'environnement général. Ce niveau de planification n'est donc pas limité aux seuls individus ou groupes dont les intérêts particuliers et/ou collectifs peuvent être remis en cause, mais ouverts à tous ceux qui tiennent à défendre une valeur considérée comme utile à la société.

Cinq autres peuvent jaloner ce niveau de décision participatif:

- une information sur la ressource à gérer sur le niveau territorial concerné et sur les aspirations de la population: analyse de la situation actuelle;
- une définition des besoins et une expression des différents objectifs des acteurs: réflexion sur la situation souhaitable;
- une élaboration des orientations et des objectifs généraux selon certains critères d'appréciation;
- un inventaire des solutions réalisables pour atteindre les objectifs souhaités;
- enfin, un arbitrage politique, affiché comme tel et légitime en tant que tel, peut intervenir pour sanctionner toute la démarche. Ce choix politique d'opportunité résulte alors d'un processus décisionnel démocratique. Il ne peut donc pas être dévolu aux acteurs de la société civile.

2) Un niveau technique

Ce niveau décisionnel doit avoir lieu lorsque l'utilité publique d'une action n'est plus remise en cause dans son principe. La participation porte alors sur les différentes possibilités techniques de réaliser la solution retenue. Elle permet une compréhension des enjeux socio-économiques, une meilleure intégration des intérêts collectifs et un enrichissement de l'évaluation de l'utilité publique des actions envisagées.

A ce stade, le niveau territorial de participation est plus étroit que précédemment. La participation peut être focalisée sur les individus et les groupes, dont les intérêts particuliers et collectifs sont directement impliqués par l'aménagement projeté.

Le choix de l'action représentant le meilleur compromis en fonction des critères retenus peut être opéré en trois étapes successives:

- examen des actions possibles,
- recueil des avis et critique des citoyens,
- décision politique sur le choix d'une action.

3) Niveau socio-économique

Ce niveau fait appel à une négociation extra-technique qui, pour l'essentiel, conserve le projet, mais associe la population à sa réalisation et à son exploitation. Il s'agit donc de faire entrer les intérêts locaux dans les logiques globales qui ont donné naissance au projet et qui en déterminent l'économie. La participation permet ici une certaine réappropriation locale des avantages du projet qui, à terme, réduit les tensions, même si elle ne les fait pas disparaître.

L'implication directe des acteurs locaux favorise l'acceptabilité du projet en permettant son adaptation au niveau territorial et à la réalité quotidienne de la population. Elle permet également d'assurer la cohérence de l'équipement avec l'ensemble des décisions d'aménagement de la région.

Cependant, malgré les efforts pour concevoir et réaliser l'équipement en harmonie avec la vie socio-économique locale, il semble difficile d'éviter certains effets négatifs secondaires. Aussi, sera-t-il nécessaire de mettre en place des mesures compensatoires pour rééquilibrer les inconvénients de l'aménagement, mais aussi pour redynamiser la structure locale.

4) Avantages de cette démarche

Cette fixation assez précise des termes de débat à chaque niveau décisionnel présente de nombreux avantages:

- elle permet de moduler la participation suivant les étapes du processus de décision. La participation, assez large au départ et peu structurée peut se formaliser progressivement en fonction du degré de maturité de la décision et de la position des acteurs;

- elle fait ressortir rigoureusement à chaque étape ce qui est négociable et ce qui ne l'est pas, afin de faire apparaître un ensemble de données sur lesquelles le débat social pourra s'engager et des propositions aboutir;

- elle favorise une intégration progressive et continue de la participation du public à la décision;

- elle permet de renouveler et d'enrichir considérablement le système de représentation démocratique traditionnel en redonnant à la décision politique son rôle légitime d'arbitrage;

- elle lève en partie la tutelle de la sphère technique sur tout le projet et lui substitue un rôle pédagogique de proposition, d'animation et de synthèse. Elle favorise donc les innovations et les expériences au lieu d'encourager la poursuite de méthodes qui ont bien fonctionné dans le passé mais qui sont devenues inopérantes;

- elle développe l'art d'imaginer des solutions qui soient visiblement des compromis. Ce qui donne aux personnes impliquées l'impression que leur opinion a été prise en considération. Elle constitue ainsi un jalon de l'impact de la participation du public sur la décision finale;

- elle permet la recherche de consensus minima sur les principales orientations ce qui oriente la procédure vers des compromis et des mesures compensatoires plutôt que vers des considérations brutales d'échec ou de succès. Elle lève donc la question de "faire ou ne pas faire" pour s'attacher à trouver la meilleure solution possible pour résoudre un problème hydraulique;

- enfin, par une référence constante aux populations et aux milieux, elle permet une prise en compte globale de l'espace, de la ressource et de l'environnement à tous les niveaux.

D) Participation et mobilisation sociale

Enfin, il convient d'évoquer un dernier point très important, et qui n'est pas sans poser de problème, c'est celui de la demande sociale de participation. Les chapitres précédents ont en effet évoqué les possibilités d'offrir au public une intervention positive et constructive dans les décisions qui le concerne, mais il reste le problème de donner au public des raisons d'intervenir, et qui plus est, dans des actions collectives.

En effet, avec ce qu'on a appelé la crise du militantisme et du mouvement associatif et son corrolaire, la montée de l'individualisme, la mobilisation sociale autour des actions collectives s'est fortement réduite.

Pour relancer la participation, il apparaît donc nécessaire de créer de nouveaux engagements et de nouvelles identifications et de promouvoir ou restaurer des fins collectives. Les acteurs se mobiliseront alors autour d'enjeux, de thèmes ou de projets qu'ils jugeront importants ou pertinents.

Deux types d'actions semblent pouvoir être menées pour renforcer cette mobilisation sociale:

- une action institutionnelle,
- une action de sensibilisation à l'environnement.

Pour illustrer cette proposition, il est intéressant d'étudier un exemple de mobilisation sociale autour d'un projet hydraulique. Il nous est fourni par le cas de l'aménagement hydraulique de la vallée du Calavon et du sud-Lubéron.

La vallée du Calavon et le sud-Lubéron forment la partie sud du département du Vaucluse, entre la vallée du Rhône à l'ouest et le milieu préalpin à l'est: le bassin d'Apt (vallée du Calavon) et le pays d'Aigues (sud-Lubéron) sont délimités au nord par les monts du Vaucluse et au sud par la Durance, cette région est partagée en deux par le massif du Lubéron.

Le climat de type méditerranéen de la région se caractérise par une pluviométrie annuelle comprise en moyenne entre 600 et 900 mm en fonction de l'altitude, et un déficit chronique en eau de 400 à 600 mm pendant la période végétative. Il apparaît bien que ce manque d'eau soit un facteur limitant pour l'agriculture qui, par ailleurs, bénéficie d'un type de sol, d'un ensoleillement et d'une température de qualité.

Dans le département du Vaucluse, 47 pourcent de la SAU sont irrigués. Ce rapport n'est que d'environ 3 pourcent dans la vallée du Calavon et du sud- Lubéron.

Les ressources en eau locales sont très faibles et ne constituent pas une solution à l'échelle de l'ensemble des besoins à satisfaire (les réseaux d'eau potable sont d'ailleurs constitués à partir de la Durance). La difficulté technique d'amener d'eau a, jusqu'à présent, tenu le Calavon et le sud-Lubéron intérieur dans un type d'agriculture au sec. Ce type d'agriculture présente des risques importants les années de faible pluviométrie et limite les possibilités d'adapter les cultures à la demande des marchés.

Le programme d'aménagement hydraulique a donc pour objet de créer des réseaux de desserte en eau permettant prioritairement la satisfaction des besoins d'irrigation et accessoirement, l'utilisation d'eau brute pour tout usager domestique, industriel ou urbain.

Le projet, conçu par la Société du Canal de Provence, est constitué d'un réseau collectif et de plusieurs équipements de petite hydraulique.

En ce qui concerne la participation publique, trois entités locales ont joué un rôle important dans le projet d'irrigation:

- les institutions locales,
- la profession agricole,
- la population locale.

1) Les institutions locales

Les élus locaux de 49 communes du Lubéron se sont groupés en un syndicat mixte pour former le parc naturel régional du Lubéron. De par sa structure et sa mission, le parc naturel régional est un élément essentiel d'animation et d'information pour le projet hydraulique (le périmètre du programme d'irrigation est sensiblement le même que celui du parc).

Dans le cadre du projet, de nombreuses réunions rassemblant les élus, les représentants agricoles, les animateurs du parc et parfois la Société du Canal de Provence ont eu lieu. Parallèlement, des commissions se sont constituées pour réfléchir sur le développement du pays avec l'irrigation. Enfin, des plans d'occupation des sols ont été mis en place pour planifier l'urbanisme et garantir la sauvegarde du milieu agricole et naturel après l'arrivée de l'eau.

2) *La profession agricole*

Très mobilisés pour faire aboutir le projet, les agriculteurs sont épaulés par un mouvement coopératif et de groupements de producteurs très importants. Mais outre le projet hydraulique, deux groupements de développement agricole (GDA) ont poursuivi une réflexion avec le parc naturel régional et la chambre d'agriculture sur:

- la situation actuelle de la fonction agricole et son évolution prévisible,
- l'installation des jeunes,
- la formation des agriculteurs.

Ainsi, avec le projet hydraulique, c'est tout un programme de développement agricole qui est étudié. Les organisations agricoles sont aidées en cela par la Société du Canal de Provence, dont la mission est également de mettre en place des mesures d'accompagnement, en accord avec les projets hydrauliques (assistance technique, actions foncières et de reconversions, amélioration de la production, maintien des activités en milieu rural...).

3) *La société civile*

Outre les usagers de l'irrigation et les responsables locaux normalement impliqués dans le projet, la population du Lubéron a été invitée à réfléchir et à s'exprimer sur le programme hydraulique par le biais d'un projet culturel.

Le programme d'animation culturelle s'est proposé:

- de créer une réflexion et une mobilisation sur l'avenir des pays du Lubéron, sur la place de l'agriculture et le problème de l'eau,
- de faire connaître le projet d'irrigation,
- de recentrer le rôle prépondérant des agriculteurs dans le pays,
- de créer un projet pédagogique autour du projet d'irrigation,
- de diffuser des films, des expositions et des pièces de théâtre sur le thème de l'eau et de l'irrigation.

Pour réaliser ce projet, l'association culturelle s'est dotée de nombreux moyens, notamment:

- une radio locale,
- un journal,
- une équipe de travail.

Le projet d'irrigation de la vallée du Calavon et du sud-Lubéron, exposé très brièvement ici, n'est pas un cas exemplaire généralisable, mais il montre plusieurs voies vers lesquelles une participation bien entendue pourrait se diriger.

Tout d'abord, il semble que la formule institutionnelle qu'est le parc naturel régional a réussi à transformer les espaces de proximité en espaces de solidarités actives. Cette organisation ascendante et volontaire a permis de trouver un niveau territorial d'intervention du projet qui correspond à une échelle spatiale appropriée pour gérer le problème hydraulique posé. De plus, cette structure revalorise le niveau local et son identification par le public pour créer une dynamique territoriale de développement qui mobilise toutes les ressources de la région.

Par ailleurs, l'action conjuguée du parc et des organismes agricoles a fait en sorte que le projet ne soit pas une fin en soi, mais plutôt un moyen de réfléchir sur la valorisation et le développement de la zone d'accueil. La stricte rationalité du projet est alors dépassée pour faire place à une réflexion générale sur l'aménagement et l'évolution à long terme de la région.

Enfin, le programme culturel, en valorisant les solidarités locales, a redonné aux habitants le souci d'appartenance et d'identité à leur espace local et leur a permis de retrouver les fonctions et les usages des différentes composantes de leur milieu. Par cette appropriation individuelle des enjeux locaux et spatiaux de la gestion des ressources en eau et de l'aménagement du territoire, une participation active et positive s'est mise en place. Une citoyenneté active a pu naître alors de la reconquête par le public de son environnement.

Conclusion

La participation dans le domaine de l'eau est fréquemment envisagée par les maîtres d'ouvrage comme le moyen d'obtenir une adhésion publique très large autour d'un projet hydraulique spécifique et bien défini. Cela permet principalement de faire face à une baisse croissante de légitimité de l'action politico-administrative et d'apaiser sinon résorber certains conflits inhérents aux projets hydrauliques. Mais très rarement la participation publique représente l'occasion de débattre sur les problèmes spécifiques de la gestion de l'eau sur un territoire donné ou d'élaborer conjointement les grandes lignes d'un programme qui tienne compte de la pluralité des valeurs et des intérêts des usagers de l'eau.

Il en ressort, malgré la création d'organes décentralisés de coordination et le développement de mécanismes de participation, une vue encore trop fonctionnelle, parcellisée et autocratique des actions d'aménagement hydraulique. Dans ce cadre, la participation ne fait qu'amplifier le malaise et augmenter l'incompréhension, car elle apparaît au public comme limitée et perverse. Il s'ensuit alors une grande désillusion, et un effet cumulatif de désengagement en ce qui concerne la gestion et la planification de l'eau. Cela conduit au mieux à un cynisme à l'égard de la participation et à une passivité civique et, au pire, à des conflits stériles et à des réactions violentes.

Il a été possible d'établir, au cours de cette étude, que l'information multilatérale était un préalable indispensable à la participation et qu'elle était une des expressions de la complexité du domaine de l'eau et de ses usages parfois contradictoires.

Il est apparu ensuite qu'une meilleure participation pouvait être obtenue par un emploi continu, diversifié et complémentaire des divers outils de participation disponibles à l'intérieur d'un programme cohérent de participation.

Il a été réaffirmé ensuite que, pour appréhender la totalité des enjeux à court terme et à long terme, la participation ne pouvait être que basée sur l'élucidation progressive des niveaux de décision et de responsabilité, selon des règles communes acceptées et respectées.

Par ce processus, il est possible d'aboutir à un consensus minimum qui intègre progressivement le public à la décision, qui s'appuie sur le système de représentation politique et lève en partie la tutelle technique sur les projets. Il développe l'art d'imaginer des solutions qui soient visiblement des compromis et autorise la prise en compte globale des espaces, des ressources et des milieux.

Enfin, dans le domaine de la gestion des eaux, il semble nécessaire que la volonté d'aménagement et de développement cherche à se structurer à des niveaux plus conformes aux impératifs de la ressource et aux transformations sociales qui ont affecté la société dans son ensemble. Ainsi, pour mobiliser les potentialités humaines et les forces locales, les actions d'aménagement doivent s'attacher à la réalité concrète des milieux, des ressources naturelles et redynamiser le tissu socio-économique local.

La participation pourra être alors continue, prenant en compte des objectifs généraux à long terme et ne se limitant pas uniquement à la réalisation d'un projet. Elle sera également diversifiée pour associer des acteurs ayant des logiques différentes dans la gestion concertée d'un même patrimoine naturel, susceptible d'usages multiples.

Il est certain qu'une telle approche de la participation est un idéal, car elle fait un pari sur la capacité du public à conduire et à mener des entreprises globales, cohérentes et respectueuses de l'environnement. Elle fait également un pari sur la capacité des élus et des pouvoirs publics à relancer la démocratie, accepter et gérer les conflits et rassembler les intérêts sociaux contradictoires autour d'une politique globale et intégrée de l'eau.

Cette approche est cependant une nécessité car elle permet, à une époque de récession économique et de changement institutionnel, de concevoir un aménagement de l'espace qui valorise les potentialités et les ressources naturelles et humaines disponibles.

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THE LAGOA SAO PAULO PROJECT

*Maria Isabel Granja*⁴³

History

In order to supply the growing demand for electricity in the area, CESP - Companhia Energética de Sao Paulo (Sao Paulo Light and Power Company) carried out a series of studies of various rivers in the State of Sao Paulo (Brazil) with a view to utilizing their power potential by means of dams and reservoirs.

One of the dams to be built is Porto Primavera, on the Parana River on the border between the States of Sao Paulo and Grosso do Sul. This dam will have an initial installed capacity of 1 400 MW when it starts operating, probably in 1994.

The Porto Primavera reservoir will be about 250 km long, 13 km wide, and its surface will have a total area of approximately 2 500 km².

The reservoir will flood a Forest Reserve in the state of Sao Paulo and uninhabited lands in Mato Grosso do Sul.

On the Sao Paulo bank one of the areas to be affected is the Lagoa Sao Paulo region, apart of the Forest Reserve in the municipality of Presidente Epitacio, where 500 farm families live. All these families occupy, but do not own, the land and for this reason they will have no legal right to compensation for the loss of the land, except for a small indemnity for the improvements that might have been introduced by them. The great majority of the families practice subsistence agriculture.

In accordance with its policy of encouraging the preservation of the natural environmental balance, the multiple use of the reservoirs and the activities that already existed - so as to avoid harmful economic and social side effects - CESP made a thorough study of the region, covering the physical environment (soil, subsoil, climate and hydrology), the biotic environment (fauna and flora) and the social environment (population situation, urban population density, agrarian structure, infrastructure and urban system, health and sanitation, economic activities, education, recreation, landscape, cultural, archaeological and historical aspects).

That study provided for a programme of activities aimed at minimizing the environmental impact caused by the project and indicated relocation as the best solution for the destitute people affected by the future lake.

⁴³ Centrais Elétricas Brasileiras S.A. - ELETROBE

As has been said, the great majority of the farm families practice only subsistence farming. As they live on lands they do not own, entitled only to a compensation for the improvements they had introduced on the lands (in the present case, not significant) they would be obliged to abandon the area where they live as they are entirely dependent on their farming activities.

They will not, on their own, be able to re-establish their previous situations, nor be absorbed by farms in the region as hired farmhands. Above all, they are not qualified or prepared to adapt themselves to city life, the only other alternative. The cities of the region, by that time, will have very little capacity to absorb additional workers and thus cannot accommodate such a large contingent of families, most of whom have no city job skills.

On top of this social problem is the economic one. The impact on the budget of the city of Presidente Epitacio will be negative, due to the interruption of agricultural production.

CESP, responsible for the dam, decided to study the integrated resettling of the population, including the affected community in the decision-making process. Based on the results of the studies, it was decided to conduct a planned relocation, the destitute farm families being moved to another agricultural area.

Development

2.1 Choice of Land area for Relocation of Population

Various regions were considered. The choice fell on a tract of farmland with a low level of occupancy, located in the vicinity of the Forest Reserve and which has the following characteristics:

- it belongs to the state and is occupied by 29 large landowners only;
- it has a low level of occupancy and use;
- it is located about 15 km from city centres;
- it is connected with those cities by unpaved municipal roads which can be used almost all the year round;
- the soil is suitable for farming;
- the topography is favourable for mechanized farming.

2.2 Criteria used for Selecting the Beneficiaries of the Project

All the population involved has been registered (including the landowners already settled and the newcomers). Priority for establishing who is to be served first was decided according to the following criteria:

Location of the land and characteristics of the properties

(a) Location of the plots

- in the Forest Reserve, within the area to be flooded and out of the project area;

- out of the Forest Reserve, within the area to be flooded and out of the project area;
- out of the Forest Reserve, out of the area to be flooded and within the project area;
- out of the Forest Reserve, out of the area to be flooded and out of the project area.

(b) Characteristics of the plots

- Occupier of the land
- Share-cropper.

On this basis the priorities for access to the land were divided into two categories. These two categories comprised 497 families. Together they constituted all the beneficiaries of the project. They were structured in the following manner:

- 1st category - Land occupiers and share-croppers practising subsistence farming. These people will have to leave the area as a consequence of the flooding and have no right to compensation for the lost land except for the low value of improvements. This is placed in the category of first priority because they have no alternative activity and therefore would have to emigrate without definite prospects.
- 2nd category - Tenant farmers, partners and hired farmhands on lands to be used for relocation (Project Area). Because of the project they would lose their land and their means of survival and remain without any alternative activity in the area.

The large landowners in the Forest Reserve area were not given priority because, with the indemnity received for the improvements, they can settle on other sites. Such is also the case of the inhabitants of the flooded areas whose homes are neither within the Forest Reserve nor in the project area.

Initially, the following data on the project population was gathered:

- Age of the head of the family
- Size of the family
- Length of period of residence
- Relationship with the land
- Degree of occupation of soils
- Area cultivated
- Number of persons working on the holding
- Ownership of other rural land

2.3 Characteristics of the project

- The Project Area has been divided into farm plots so that all the beneficiaries can be settled.
- One Main Service Centre and four Secondary Service Centres are planned.
- Of the 29 large landowners in the Project Area, one will remain on the property he occupies. This group has been maintained with the intention of preserving a pattern of production considered highly positive, as this operation presents a high technological level and employs a large number of farmhands.
- Each plot has an average area of 15 ha.
- The plots are mainly suited to annual crops, such as rice, corn, beans, peanuts, cotton, and for secondary crops, such as cassava manioc, castor beans and others.
- It has been suggested that a house and its annexes should be constructed on each plot with shed, orchard, pigsty and a small subsistence farming area. The back of the plot could be occupied by a small stable. The rest, approximately 90 percent of the total, is to be devoted to commercial farming.
- Four types of houses are suggested. Three of three bedrooms and one of two bedrooms, with a built up area varying between 60 and 70 m², the choice being left to the beneficiary.
- The Main Service Centre is to consist of one building for the cooperative and its administration offices, mini-market, processing mill, warehouse for agricultural and livestock supplies, repair and maintenance shop, a primary school, a health centre, a hall for social and community activities, and eucumenical church, an area for sports activities and housing for technicians who are to take part in the development of the farming colony.
- The three Secondary Service Centres will have one small administration office, doctor's office, warehouse, hall for community use, school with four classrooms and annexes, football pitch and playground.
- The location of these centres is planned so that all beneficiaries can reach them on foot within an hour at the most.
- The schools are for elementary education, 1st to 4th grades, through the Community School Action Units (UEACs).
- The Service Centres are to be located along the highway axis, so that no beneficiary will have to travel more than 6 km to reach them.
- The road system has been planned to give access to the plots and to facilitate the transportation of farm produce. It consists of a network of roads connected to the main highway axis.
- The main highway connects two cities.

- To protect the shores of the reservoir, a recreation area has been planned, controlled by the Main Service Centre.
- Protection of the river network has been studied and will be ensured.
- The division of the land into plots takes advantage of the local topography, so as to facilitate the use of farm machinery.
- Administration and technical assistance have been taken into consideration.
- As to sanitation, individual water wells have been planned for the beginning to be replaced at a later stage by a piped water supply system and the installation of cesspools for sewerage.
- Rural electricity for domestic and commercial use.
- Communications, including radio telephone.
- The first relocations took place in 1980. At the end of the first stage when 200 families had been relocated, the economic-financial analysis showed that installation of water and electricity on the plots was unfeasible.
- For this reason, the project has been revised and the creation of five agrovilas (urbanized land divisions in the rural area) was proposed to those who desired these services. In the new situation, the Main Service Centre as well as Secondary Service Centres were integrated within each of the agrovilas.

2.4 Consulting the affected population

As soon as the beneficiaries of the project had been defined, the consultation process began.

The main topics raised were:

- location of the houses: according to the new concept they could be located either in the agrovilas or on the plots;
- distribution of the buildings on the plots: each beneficiary could decide on improvements to be made to the plots;
- choice of neighbour;
- financing for the construction of the houses if desired by the beneficiary;
- planning the move: in its most simple aspects such as meals, as well as the most complex ones, such as making the best use of the removal vans and checking on the subsistence conditions of the plot holders in their new start in life;
- training programme: aiming at making the farmers capable of managing not only their own plots, but the enterprise as a whole as well. The programme comprised two: occupational and general;

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- The occupational component involved four distinct topics: rural credit, agro-industry, cooperatives and marketing - all developed with the participation of the organizations responsible for their supervision;
- The general component involved elementary education for beneficiaries' children, and comprised basic instruction, complementary to occupational training and included learning to read and write;
- identification of local leadership: through informal consultations with the people affected, thus avoiding leadership imposed from the outside.

The facts were gathered by means of interviews, field surveys and questionnaires.

- "Demographic and Socio-Economic Survey": a questionnaire covering among other aspects, the family group, period of residence and the possibilities of legalizing the land occupancy, current land use, farm activity, livestock activity, fish farming activity, relationship with neighbours and school needs.
- "An Opinion Poll for the Beneficiaries of the Residential Nucleus": involving, among other topics, transportation aspects, location of residence (agrovila or property) and for house-purchase loans.

2.5 Results of the Community Consultation

As regards the questions raised before the community, the results were as follows:

- location of the houses: each group organized itself in a certain way. The wish to live on the lots predominated; however, a tendency to move to the agrovilas could be noted. This predominance can be attributed to the fact that relocation was initiated with the plots and many families were already living there when the agrovilas were constructed.
- distribution of the buildings on the plots: the majority of beneficiaries chose their own distribution. In general the configuration of their original properties was reproduced. There have been minor modifications on the part of some beneficiaries.
- choice of neighbour: the beneficiaries grouped themselves traditionally, choosing relatives for neighbours or partners in joint farming activities. Only after these natural groups had been formed were the plots distributed. All choices were strictly respected and up to now there have been no conflicts nor requests to move. The beneficiaries who did not succeed in joining a group (about 10 percent) had their plots designated by CESP.
- financing the building of the houses: all the beneficiaries refused to accept loans. They chose to build their own houses jointly, all hands pitching in, or on their own.
- planning the move: all activities were defined by mutual agreement of both parties, the beneficiaries and CESP. The established plan was followed without any problems.
- training programme: defined by mutual agreement. 80 percent of the community participate in the two components defined above.

- identification of local leadership: local leaders were identified, however difficulties arose concerning community action and the cooperatives, as some concepts were distorted in the sense that certain groups enjoyed privileges.

Through the Community School Action Units, supported by CESP technicians, the beneficiaries changed the leadership and proposed new community actions.

The first change was a return to the cooperative plan's basic principles, with a view to treating all associates equally. The existence of privileged groups had resulted in the cooperative deviating from its original objectives. At the moment the purchase of a community milling machine is envisaged, so that processed cassava can be marketed.

At the request of the beneficiaries, one of the Community Action Schools became an Elementary School (EEPG), teaching the first to the eighth grades.

a project for the safeguard of the cultural heritage was initiated to protect local handicrafts endangered by the new technology.

In addition, changes were made in the system of health care. A mini health centre was created, manned by health agents. These agents belong to the community and have been trained to give first aid, vaccination, etc. The agents send the more serious cases to the doctor who is on duty all day at the central health centre.

A dental care office is now being built.

Technical agronomic assistance has been definitely integrated in the production process. In the beginning the beneficiaries mistrusted the experts and did not accept their advice easily.

The road system has been improved and is now suitable for all year round use. There are now two intercity bus lines and one serving the project area.

A security system is being created.

2.6 Status Report

By the beginning of 1986, when this paper was written, 460 families had already been relocated. The cooperative had been created (one central unit plus four others and two warehouses) as well as three school units (Community Action - UEAC). An elementary school (EEPG), 10 houses for teachers, a recreation area of 5 400 m², health centres with a house for the attendant, one support camp of 300 m², 150 km of connecting roads, 19 km of streets built in the agrovilas and a Community Centre constructed by the Power Company and another constructed by the beneficiaries of agrovila 4.

The project area is distributed as follows:

- Total area of the project: approximately 10 000 ha.
- area of farm plots: 8 250 ha.
- area occupied by agricultural infrastructures: 200 ha.

Many other experiments have already been made in Brazil with a view to resettling rural populations. What makes the Lagoa Sao Paulo Project unique is the consultation of the community involved and the subsequent joint planning of some of the activities. We attribute the essential difference of the project to this fact because it is observed that in addition to the aspects reported, the beneficiaries have developed a community consciousness. The importance of work and the attachment to a small property attained special dimensions. Until now, only one family left its plot and moved to a nearby city. Today the beneficiaries are small rural proprietors in the process of evaluating their rights and obligations.

Having a common goal, they stick together to achieve this goal and they regard the Lagoa Sao Paulo Project as highly positive.

Another aspect considered to be important concerns the political context in which the project took place. The community that lived in the forest reserve was already organized to defend its land and to assert its right to work the soil, as they lived under the threat of being expelled by the land owners. This experience was very valuable as it made it possible to settle the disputes of the beneficiaries and, above all, it helped to adjust the project to the beneficiaries' requirements, who themselves participated in the decision-making process.

Lastly, this experience showed that even when the people affected by a process like this do not insist on participation, those responsible for the accomplishment of the project can involve them in the decisions concerning their living conditions. The results proved that such an attempt is definitely worthwhile.

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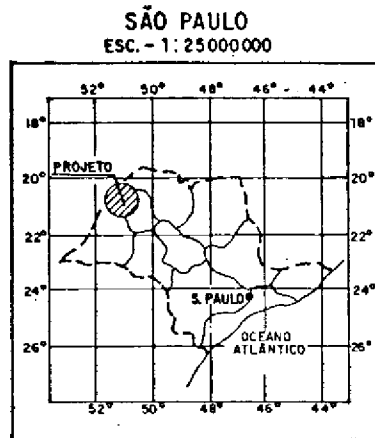
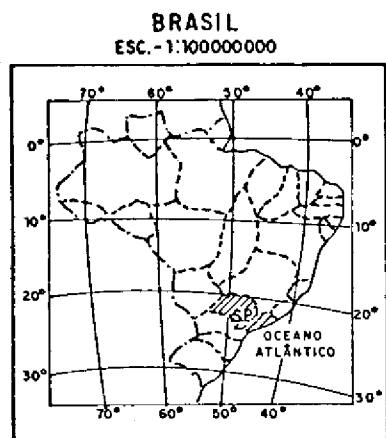
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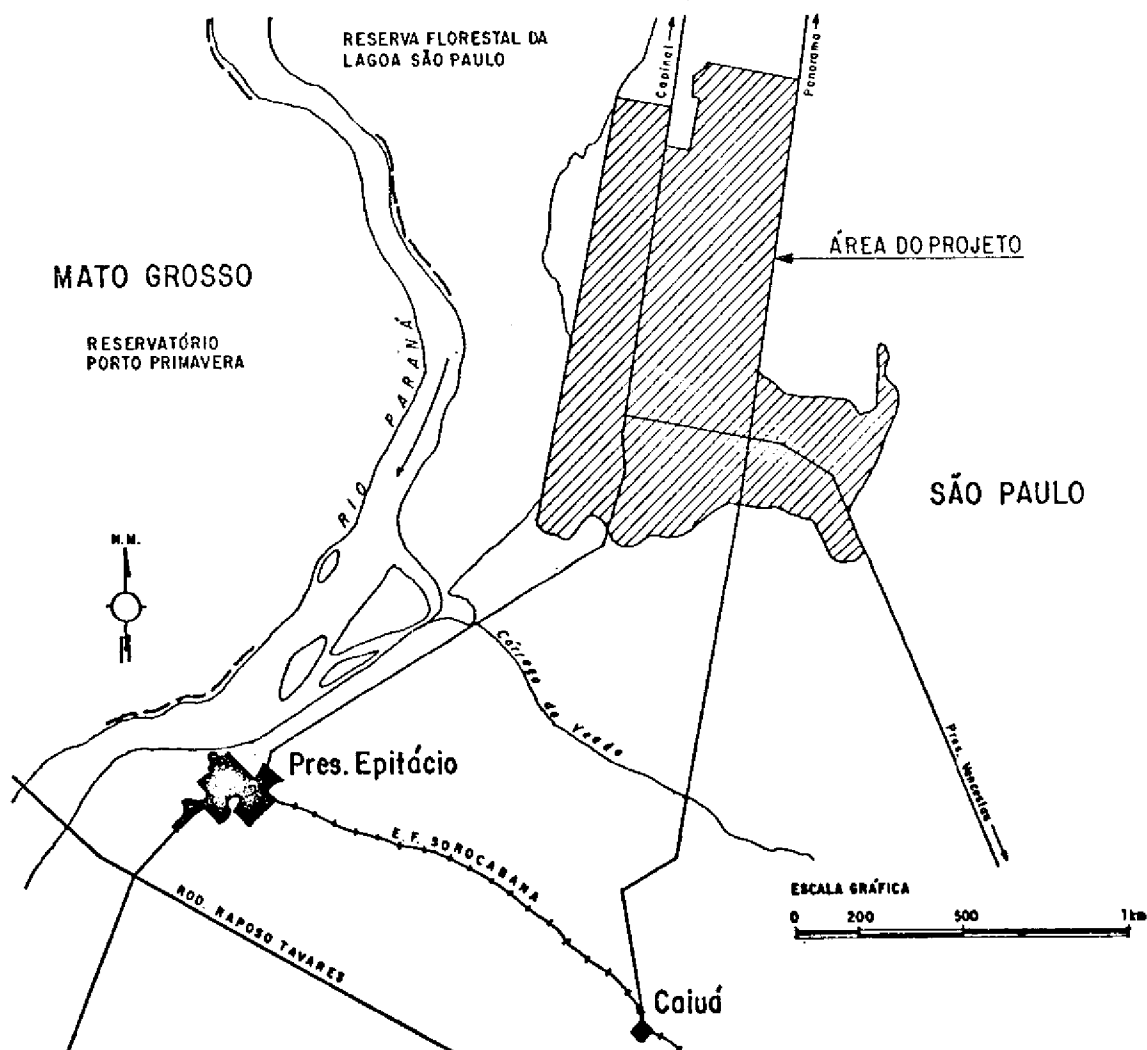
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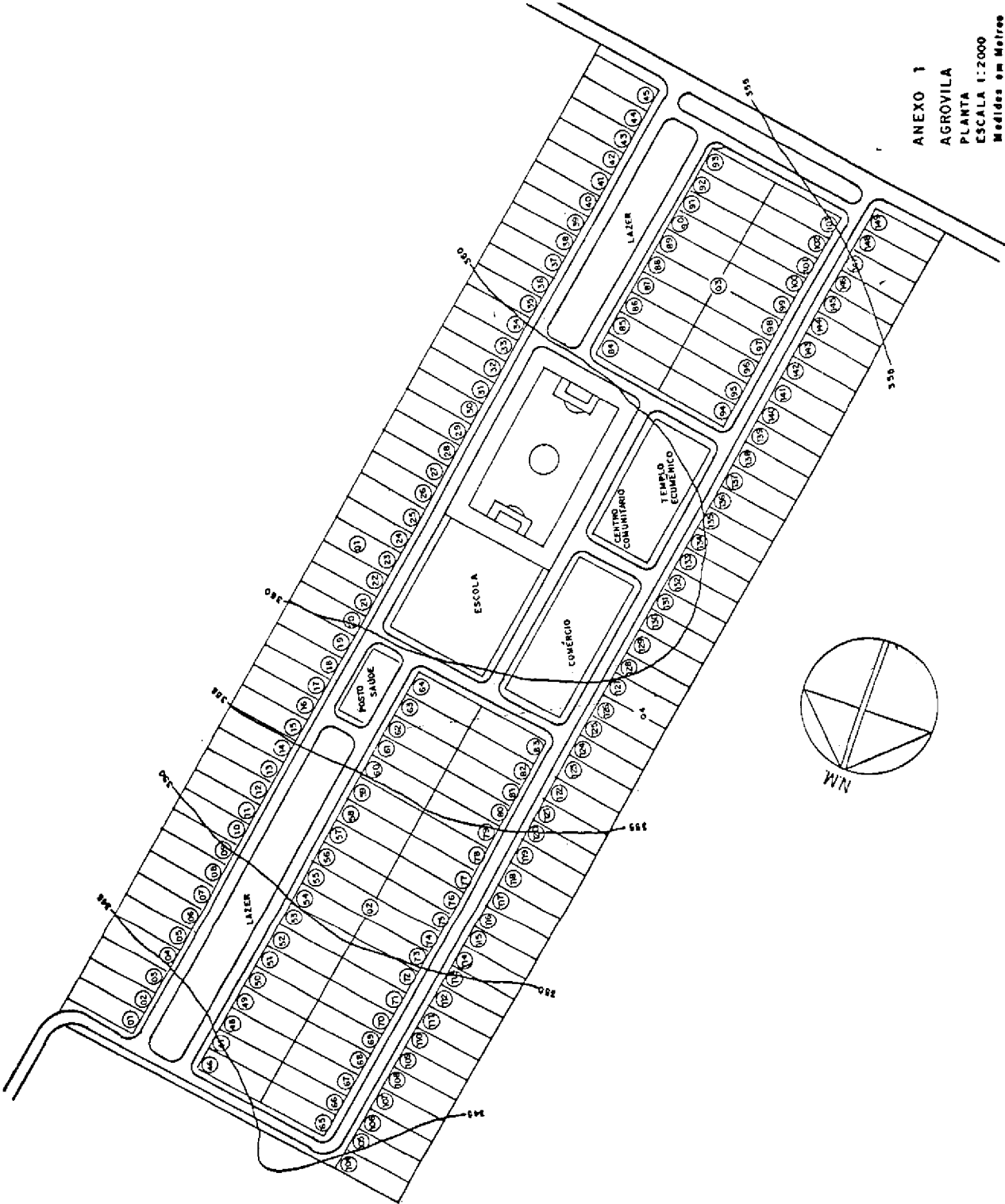
CESP - Sao Paulo Light and Power Company - Booklet NCAL/PE/001/82, containing the questionnaires used for the Lagoa Sao Paulo Project.

LOCALIZAÇÃO DO PROJETO

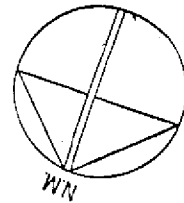


CROQUÍ DE ACESSO AO PROJETO

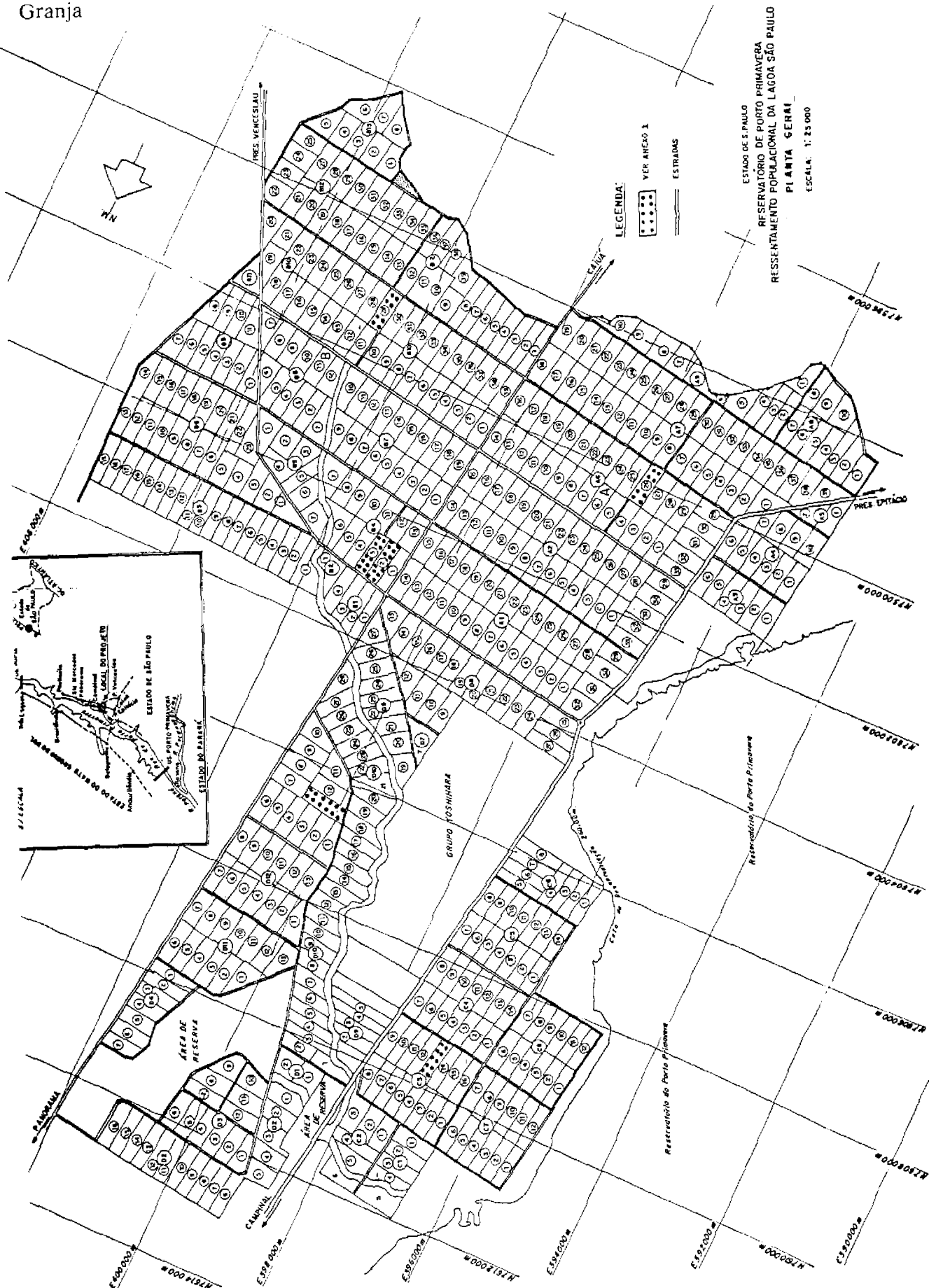




ANEXO 1
AGROVILA
PLANTA
ESCALA 1:2000
Medidas em Metros

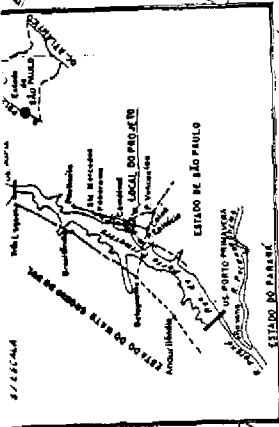


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LEGENDA:
 VER ANEXO I
 ESTRADAS

ESTADO DE SÃO PAULO
 RESERVATÓRIO DE PORTO PRIMAVERA
 RESENTEAMENTO POPULACIONAL DA LAGOA SÃO PAULO
 PLANTA GRANJA
 ESCALA: 1:25.000



PAPER 46

THE ROLE, OPERATION AND POSSIBLE IMPACTS OF SUPPORT COMMUNICATION ON WATER RESOURCES DEVELOPMENT

*Femi Olokesusi*⁴³

Introduction

National governments in the developing world and international agencies have invested huge sums of money, human and material resources to facilitate the development of water resources for a number of purposes. The most common objectives of such developments which are in the form of dams, reservoirs and diversion canals have been to provide water for irrigation, hydropower, navigation, recreation, industrial and domestic consumption as well as water quality control and flood control.

Tremendous pressure is brought to bear on development agencies in the developing countries to speed-up efforts to combat poverty, ill-health, drought, famine and all other miseries associated with the syndrome, and water being a basic human need has received a lot of attention.

Many water projects like the Aswan High Dam in Egypt, Kainji and Bakolori in Nigeria, Volta in Ghana, Tucurui and Itaipu in Brazil, Tarbela and Mangala in Pakistan and Rajangana in Sri Lanka among others, have been embarked upon in an attempt to provide water for socio-economic development. But a comparison of the explosive population growth in these countries with available water supplies underlines the need for more water. Nevertheless, most Third World countries have not developed their water resources as extensively as have the industrial countries, and they face some specific challenges in an era of scarce and costly water. Third World economies are still largely agrarian, and irrigated agriculture claims 85 - 90 percent of their developed water resources. Satisfying expanding urban and industrial demand while meeting the food needs of growing populations will require much additional water. However, these nations face capital and energy constraints as well as negative environmental impacts, which might reduce the pace of water resources development. (Postel, 1985).

The importance of reservoir projects is illustrated by the fact that by the year 2000 it is estimated that the portion of the world's streamflow regulated by reservoirs will increase from one-tenth to two-thirds. (Freeman, 1974).

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Unfortunately, numerous but perhaps avoidable negative impacts have become evident in most water management projects. In Nigeria, the Bakolori Dam project in Sokoto State led to social unrest, loss of life, extortion, displacement of populations without resettlement and large-scale destruction of forest.

A report of the Agency for International Development on the prospects for the Ambukulao Dam in the Philippines notes that "the cutting of timber and the subsequent loss of water retention capacity of land surrounding the reservoir has resulted in massive silting of the reservoir, reducing its useful life from 60 to 32 years". (USAID, 1979).

Similarly, the designers of the Mangala dam in Pakistan projected a life expectancy of at least 100 years for the reservoir. What they did not reckon on was the effect of mounting population pressure on the watershed above the reservoir. A combination of the axe and the plough, as land-hungry peasants push up the hillsides, is leading to a rate of siltation that will probably fill the reservoir with silt at least 25 years earlier than expected. (Eckholm, 1976) and (Table 1).

As regards health impacts, up to mid-1977, Schistosomiasis control has been implemented in thirty projects by the World Bank, at a cost of about US\$63.36 M. (O'Leary, 1982). Other international agencies have undoubtedly spent huge sums of money on disease control in the Volta, Chad, Kainji, Mangla and Matumbulu basins among others. However, it has been argued by some experts that some of these impacts would have been mitigated or reduced if planners had combined technology and communication. (Pickford, 1985; McLoughlin, 1983; Monowoski, 1986; Olokesusi, 1985a, 1985b; Ince, 1985).

Table 1 - Siltations Rates in Selected Reservoirs

Country	Reservoir	Annual siltation rate (t)	Time to fill with silt (years)
Egypt	Aswan High Dam	139 000 000	100
Pakistan	Mangla	3 700 000	75
Tanzania	Matumbulu	19 800	30

Source: El-Swaify and Dangler (1982)

Objectives

It is in the light of the above that the following will be examined: First to identify the need for support communication in water management projects, secondly, to describe the how support communication process can be planned and implemented as a component of the larger development planning and implementation processes in developing countries in general and with a view to enhancing environmental quality in particular. The paper is concerned primarily with rural areas in developing nations.

Some Misconceptions concerning rural populations

Water resources development projects are usually regarded as a strategy for socio-economic development, especially of the rural areas in the developing countries, since water helps to improve the socio-economic and physical life of society, and rural development encompasses any human activity which contributes to the establishment of improved rural welfare. (World Bank, 1975).

Rural development has also been construed to mean increased adaptive behaviour and purposeful and cumulative control of people over changes in the environment, and in themselves, so as to attain greater human welfare and better human conditions (Inyatullah, 1967; Ashcroft, 1969).

In most poor nations, dams, reservoirs and irrigation schemes are often located in rural areas, and have sometimes been built as part of regional development programmes. But in quite a significant number of poor nations, water management projects of many types are limping, delayed and often failing outright because of failure to communicate with the people - the rural beneficiaries. Although clearly distinguishable as a unique category of individuals, they remain an audience which must be better understood in a reliable, generalizable and scientific way, since their views are rarely known. This was emphasised by Marx and Engels when they described peasants as an "indecipherable hieroglyphic to the understanding of civilization". The ruralite remains an enigma to those who have not lived his life and as a result, he is often characterized in a negative light. (Rogers, 1969). Also, Prawl (1969) asserts that due to lack of understanding ruralites develop into a stereotype - the ruralite is ultra - conservative, steeped in tradition, hemmed in by custom, lacking in motivation and incentive, captive age-old methods.

These misconceptions must be corrected partly to encourage the ruralites to take part in developmental tasks, so as to ensure the success of water management projects in these difficult times. One viable strategy of achieving these objectives is the integration of support communication with water resource development programmes.

Definition of support communication

Support communication means the combined use of various communication channels (mass media, interpersonal and group), technologies (hardware and software), delivery systems (print, electronic, audio, visual, audio-visual, training, and person-to-person), for the purpose of sending messages to promote, persuade, motivate and eventually induce behaviour modifications, thereby contributing to achieving the major goals and objectives of a particular water resource development programme.

The need for support communication

A significant reason for the persistence of avoidable impacts of large water management schemes (siltation, malaria, schistosomiasis, onchocerciasis, population displacement, etc.) is the technical/bureaucratic bias of such projects. More often than not the planners are engineers belonging to government and other agencies primarily concerned with economic and technical efficiency. This combination of technician and bureaucrat virtually guarantees the effective omission, in the earlier stages of project development, of integral feasibility components such as economics, legal/institutional considerations, social matters, and often environmental aspects, even though lip service may very well be paid to these issues (as now

required by law in many countries). To serve its purpose successfully, planning of the management of any resource, particularly one in which the entire community has a direct stake, such as water, should begin with the final uses to which people want the resource to be put. The planner should then work back to the initial situation, identifying what must be done along the way to achieve the final objectives. We know from long observation that a meaningful change brought about by man's influence on any one aspect of a water system will sooner or later induce qualitative changes in other linked systems. (McLoughlin, 1983) and (Figure 1).

Research has also produced substantive evidence showing that development and communication are strongly correlated (Beltran, 1978). At the village level, a comparative study has demonstrated clear correlations between communication and socio-economic as well as political development. (Rao, 1966). Effective support communication and interaction requires conscious efforts by members of the public and development agencies in view of the various obstacles to such relationships.

Lerner (1958) asserts that communication is an essential instrument of socialization and that socialization is, in turn, the main agent of social change. Social change itself is a condition for societal development. Quebral (1974) cites Schramm on the tasks of communication in a developing state:

1. To disseminate information that will inform citizens of opportunities, dangers and changes of the immediate and wider environment;
2. To provide a forum where issues affecting the life of the nation may be aired;
3. To teach ideas, skills and attitudes that will promote development;
4. 4. To create and maintain the consensus that is needed for the stability of the state.

Despite all these laudable objectives, there are a number of inherent criticisms levelled by both the public and governments against the role and utility of support communication in project planning. Some of these are briefly examined.

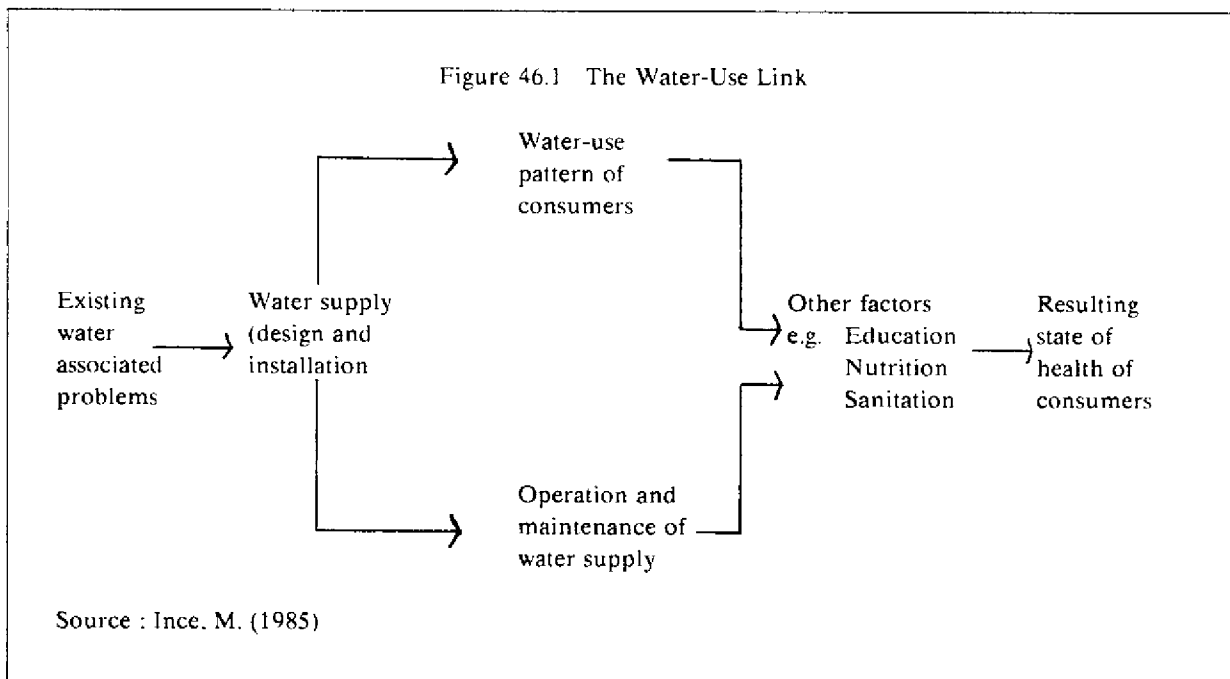
The citizen's view

i) In many rural areas, perhaps as a result of illiteracy or previous unfulfilled promises and apathy, the public often has a suspicion that there is a conspiracy involving public officials and development agencies.

ii) The ruralites believe that irrespective of their involvement in the planning process, public officials already know what they intend to do, hence, it is a waste of time and effort to participate.

iii) Usually, the ruralites receive little or no feedback concerning the impact of their inputs from public officials or agencies.

iv) Those groups which complain most and have political clout are served while those who are quiet, unorganized or inexpressive may be ignored even if they are in need.



v) Due to factionalism, it is sometimes risky to take part in the project planning and implementation processes as the powerful landowners and politicians (even if in military uniform) are behind the factionalization, in order to achieve their selfish objectives by any means available.

vi) In many developing countries, it is a fact that corruption among government, association, co-operative and village leaders, often deals a mortal blow to people's desire to be involved in the planning process.

vii) Short-term survival logic of the poor majority enhances apathy whilst suppressing participation instincts.

The Government agencies' view

On the part of the national governments and agencies, the following criticisms of support communication are common.

i) Support communication is unnecessary since the projects have been approved by the national government and international aid agencies. It is argued in any case, the people lack the organizational skills for dialogue.

ii) More often than not, support communication requires greater disclosure of information than would be required otherwise. In many poor countries such government documents are labelled 'secret', even though they are available in government and university libraries in the developed nations. Also, the tag of secrecy encourages the resource misappropriation instincts of the public officials, hence the need to retain it.

iii) Support communication implies a share in decision-making, a position that conflicts with existing requirements to operate in the general public interest, as well as making the project more difficult.

iv) The people who come to discuss land ownership and compensation are often seen as belonging to the 'political opposition' and need to be dealt with forcefully rather than by means of dialogue.

v) Many public officials still believe that even diseases such as schistosomiasis, malaria, onchocerciasis, etc. are due to voodoo, consequently, their control techniques need not be a public-affairs component of the project. This is equally true of the ruralites.

vi) Due to a low level of environmental expertise, the urge to promote scientific environmental debates is not compelling. This interrelates with the low political clout of national environmental agencies. Environmental expenditure in India, Indonesia, Nigeria, Papua New Guinea, the Philippines, Singapore, and the U.S.A. are listed in Table 2.

Country	Ratio	Year	
		Environment expenditure	GNP
India	0.0122	1982	1982
Indonesia	0.381	1982-83	1982
Nigeria (Environment Protection only)	0.000621	1980-85	1979-80
Philippines	0.005	1983	1983
Papua New Guinea	0.836	1985	1982
Singapore	1.087	1983-84	1983
United States (pollution control only)	2.00	1975-84	1975-84

Sources: Roque, (1986); Fed. Rep. Nigeria, (1981)

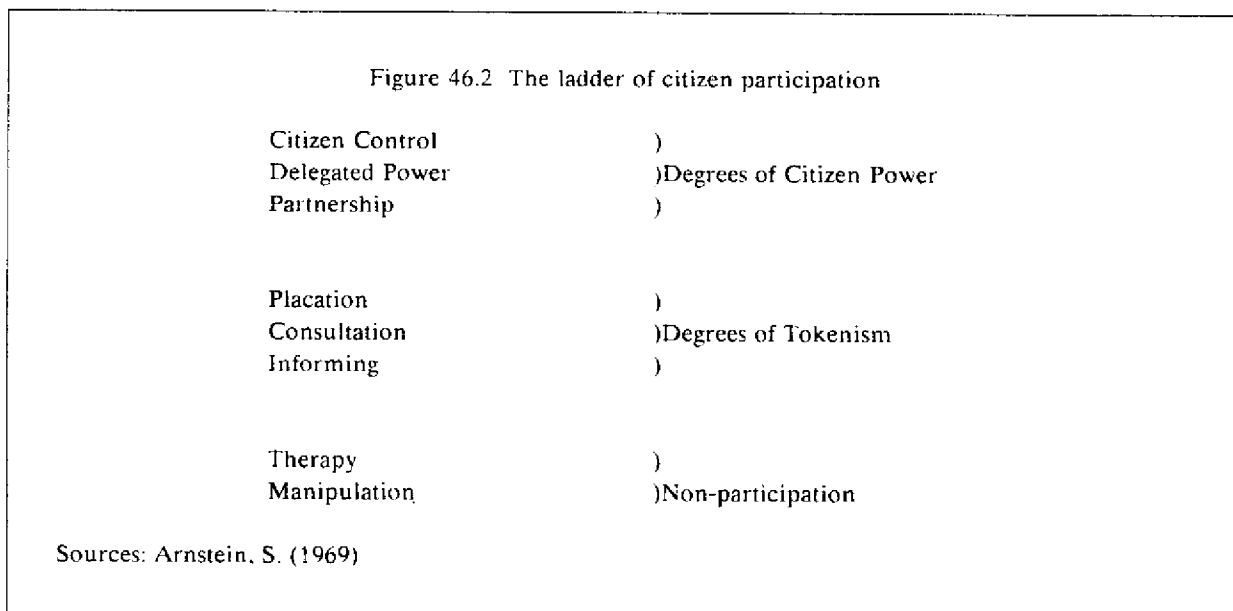
While the definitions of environmental expenditures vary from one country to another, the difference of over two orders of magnitude in the ratio of environmental expenditures to GNP is significant. These expenditures may be taken as a measure of the actual commitment to environmental values and is more meaningful than official pronouncements. (Roque, 1986).

vii) As a result of poor communication facilities, the tasks of inducing people to attend meetings and the mailing of pamphlets and questionnaires are extremely difficult, consequently the involvement of the ruralites is a significant waste of resources. (Olokesusi, 1985a).

Despite these criticisms, public involvement of one form or another often does occur, particularly as concerns aspects of development projects which are positive. This involvement usually leads to demands by pressure groups, particularly the landowners and the squatters, for compensation, resettlement, contracts, etc. Public officials or development agencies rarely inform the public concerned about possible negative impacts of projects, even the better-known ones such as schistosomiasis, and onchocerciasis.

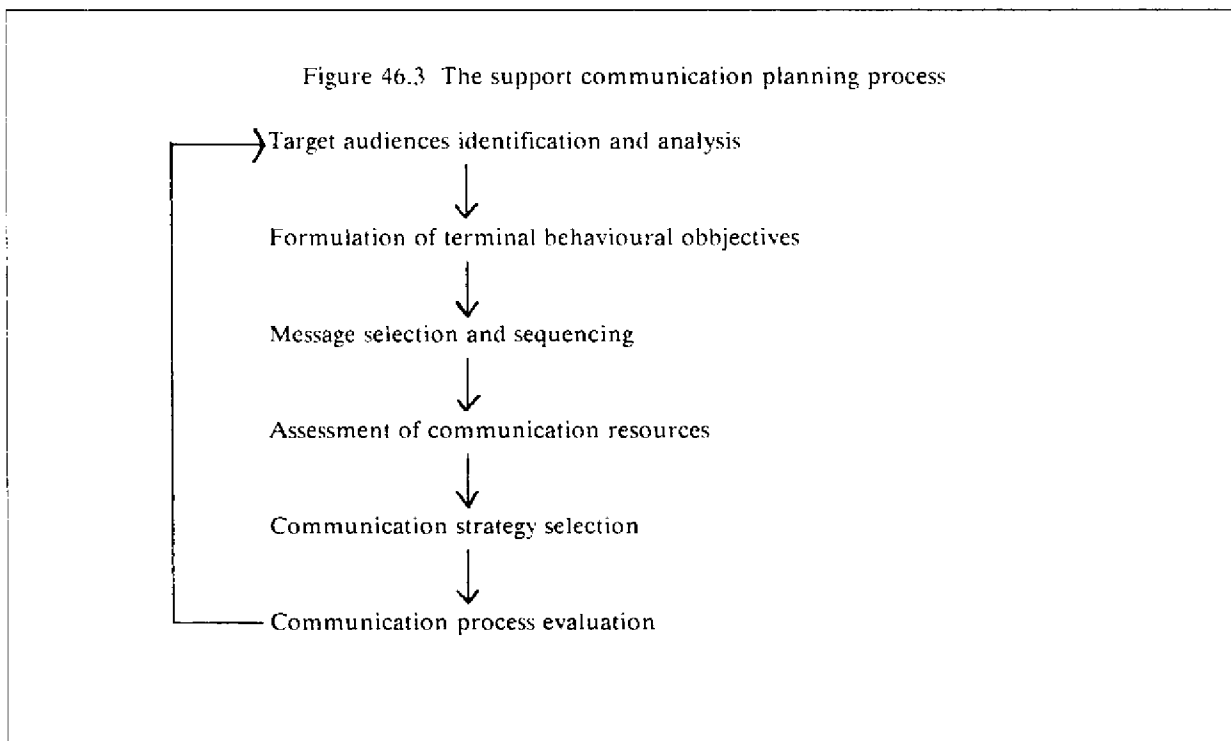
Thus, support communication in many water management projects, particularly in the developing nations, ranges from manipulation through therapy to placation, to use Arnstein's framework. (Arnstein, 1969), and (figure 2).

It is contended in this paper that the elimination of obstacles to support communication depends on altering the nature of the relationship that exists between the public and the water management agency and consequently altering the nature of the roles played by public officials and the public. One means of achieving this objective is through a planned communication programme. This programme is a systematic process of analysing, co-ordinating, synthesizing and evaluating all factors involved in the attainment of quantifiable change in the target audience's behaviour. The process is briefly described below.



The Communication Planning Process

The communication planning process discussed below in a generalized and simplified, but iterative process.



Target Audience Identification and Analysis

As soon as the project’s needs have been appraised and goals formulated, the various categories of project audience should be identified. Such audiences must include grassroots, whether organized or not, professionals, community leaders, change agents, as well as policy makers/administrators and field cadres in the project’s location.

The project planner should gather relevant social data on the audiences, categorize and analyse such data in terms of their characteristics e.g. age, sex, attitude, income and educational level among others.

Census tract records (CTR) would be adequate for a major component of this phase of the process. However, where CTR is not available or obsolete, a mini- survey could be made by the appropriate agency.

Formulation of Terminal Behavioural Objectives

During this phase, full specification of behavioural changes expected of the project (or continuing) is made. This list should describe in observable and measurable terms the desired changes in knowledge, attitudes, health, environment, and practices of the audiences. These objectives will form the basis for the project’s formative and summative evaluation. The objectives serve other functions such as evaluating the audiences, to know exactly what is expected of them and how to set about achieving them; also they facilitate the selection and sequencing of messages as well as the selection of communication approach and media. The mobilization of public support for adequately funded impact mitigation measures will require extensive public education on the dimensions of the problem and its many consequences.

Message Selection and Sequencing

The message is the translation of project behavioural objectives into concrete terms. It acts as a bridge between the audiences' existing behaviour and the terminal desired behaviour. The message selected should be checked and clarified with appropriate communication planning specialists for accuracy and completeness. However, a message must be critical and cover all major knowledge and skills required of the audience. Also the message should be simple and not conflict with the social norms of the audience. The sequencing should be from simple to complex.

Assessment of Communication Resources

Human and material resources are required in qualitative and quantitative terms. Thus, an inventory of such resources has to be drawn up as early as possible. The organizational framework for the process should be equally good and open to suggestions through a perceptible two-way communication channel. The financial resources available should determine the type of physical facilities needed and communication strategies to be used.

Communication Strategy Selection

This phase of the process involves a thorough analysis of the possible alternative methods of communicating with the audience and selecting one or a combination of the alternatives. For each possible alternative, the appropriate communication process and support materials should be listed. The previous phases will by and large determine the outcome of this phase. The use of town criers in many rural areas of Nigeria to pass information such as invitation to market square meetings, outbreak of epidemics, etc., may prove to be more effective and efficient than radio or television.

As far as possible, methods that facilitate audience feed-back should be given priority. Extensive use should be made of visuals, radio farm forums and local dialects.

Communication Process Evaluation

Since in phase two, prescribed behavioural objectives were identified, an evaluation of these should be made in order to monitor the project, provide an assessment of the impact of various inputs and give indications of the success of the project concerned.

This is a very vital phase and if done with dexterity, enables improvements to be made to the whole communication implementation process.

The above six stages are not as simple as they seem. There must be adequate commitment on the part of the government agency for the communication process to succeed. Members of the public must also show a willingness to become involved in activities beyond their homes, in particular to those activities that are pertinent to their long term social well-being. Perhaps the donor agencies should be compelled to use carrot and stick tactics coupled with factual information to convince the aid recipients of the need for environmental quality through support communication in water resources projects.

Conclusion

It is apparent that in order to develop informed water resource management plans and programmes, a deep appreciation of the characteristics, concerns and problems of the people living in the area to be affected must be gained at the earliest possible stage in the planning or decision-making process. And in an attempt to develop a cumulative effort at plan resolution, public meetings must be purposeful, that is the meetings must accomplish some tasks upon which the process of planning or decision-making is dependent.

It should be indicated that in many developing nations, governments and aid agencies should not expect informed public opinion to come into existence overnight. Painstaking and patient work will be required to wipe out the pyramid of ignorance, inertia and complacency. Also, support communication should be a component of the Environmental Impact Assessment and Review processes in these countries, and the earlier these become mandatory the better.

As a consequence of the vital role which water plays in human development, there is a need to integrate water resources management programmes with local and regional development processes. This will ensure adequate consideration of the major impacts and necessary mitigation measures. It will also encourage the use of regular monitoring, particularly of ecological and socio-economic indicators as development evaluation tools. National governments should improve public information on sanitation, environmentally desirable and sustainable development.

Finally, there is a definite need for an improved institutional framework for developing planning. Relevant public and private agencies, including grassroots, should be mobilized for relevant research and information dissemination as well as encouraging better application of foreign and indigenous resources for sustainable development.

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Annex I

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