# ECOLOGICAL GUIDELINES

# FOR

# RIVER BASIN DEVELOPMENT

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ERRATA

p. 32, 5th line from below: **'upstream'** --> **'downstream'**

Impact matrix 'Storage dam in main river system':
mitigating measure no. **8** must be no. **9**
please add mitigating measure no. **8**: **'More fertilizer is needed in irrigation project because of decreased silt load'**.

Impact matrix 'Impoldering':
please add mitigating measure no. **9**: **'Design must provide living resources (e.g. fuelwood) and sanitary facilities'**.

Impact matrix 'Arid land irrigation with riverwater':
please replace matrix with new one.

| INTERVENTION: Arid-land irrigation with riverwater<br>EFFECT - CHAINS | natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| | target variables | | | | |
| **a) location** | | | | | |
| - loss of existing landuse in project area | - | - | - | $x^{0}$ | - |
| - impact on ecosystem | $x^{1,3}$ | $x^{1,3}$ | - | - | - |
| - risk of soil salination | - | - | $x^{2,5}$ | - | $x^{2,4}$ |
| - climatic changes through increased evapotranspiration (local thunderstorms) | - | x | x | - | - |
| **b) water quantity** | | | | | |
| - regulation of river discharges: reduction of peak discharges and change in timing of the floods | $x^{3}$ | $x^{3}$ | $x^{3,5}$ | $x^{3}$ | - |
| - reduction of peak discharges can lead to a reduction of or complete eradication of wetland acreage downstream (floodplains, estuaries, mangroves and other wetlands) | $x^{3}$ | $x^{3}$ | - | $x^{3}$ | - |
| **c) water quality** | | | | | |
| - drainagewater is contaminated with agro-chemicals | $x^{4}$ | $x^{4}$ | $x^{4}$ | $x^{4}$ | $x^{4}$ |
| - stagnant surface water --▶ salination, waterrelated diseases, aquatic weeds | - | - | $x^{4,6}$ | | $x^{4,6}$ |
| **d) disposition of natural resources** | | | | | |
| - commercialization of agriculture and natural resources --▶ change in disposition of resources --▶ socio-econ. differentiation / social conflicts --▶ reduced incentives to safeguard their own environment | - | - | $x^{0,1,2}$ | $x^{0,1,2}$ | $x^{0,1,}$[illegible] |
| **e) secondary impacts** | | | | | |
| - improvement infrastructure | $x^{2}$ | - | $x^{2}$ | $x^{2}$ | - |
| - stimulus to urban and industrial development | $x^{2}$ | - | $x^{2}$ | - | $x^{2}$ |
| - development aquaculture in canals and reservoirs | | | | | |

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## SUMMARY

In the field of development cooperation, a major role is played by hydraulic engineering schemes involving dams, harbours, dikes and suchlike. They frequently form the very basis for agricultural and industrial development. This is explained by the crucial significance of water regime and water management for a country, playing an important part in many sectors of economic and social life. The many complex and far-reaching relationships existing between the river as supplier and man as user of water constitute the main rationale for taking the entire river basin as the basic planning unit, for only then can optimum use of the available resources be achieved with a minimum of social and ecological risk.

The present report provides a systematic treatment of the values, functions, potential and areas of vulnerability of river systems.

*The values of a river system are often concentrated in the wetlands*, characterized by a great variety of bird life and often also of wild game, among other things. An increasing number of countries appreciate that the vulnerability and enormous deterioration of these areas constitutes a problem, a fact reflected in the growing list of nations that have undersigned the international RAMSAR convention.

River systems fulfil spontaneous functions for human society, i.e. functions fulfilled without any need of intervention. Examples include the natural regulation of erosion and sedimentation, the spongelike action of wetlands and the water-purifying capacity of lakes and marshes. At the present time, the derangement of these functions is perhaps the major problem in river-basin management, something that is due partly to *unfamiliarity with the importance of these functions*, as well as to underestimation thereof. The enormous erosion occurring in many upstream regions is causing acute environmental problems, in upper and lower reaches alike. Through increasing levels of waste discharge, ever more tropical rivers are exceeding their capacity for self-purification. In addition, man seems increasingly bent on taking over the functions of natural hydraulic regulation himself, through construction of dams, dikes and the like. Although positive examples do also exist, the overall impression is usually that for every water-management problem solved, two more arise to take its place. An example frequently encountered is the relationship between the construction of a dam and increasing coastal erosion in the delta region, accompanied by intensified saltwater intrusion. This necessitates expensive coastal protection schemes and possibly a barrage in the estuary to counter saline intrusion. In turn, fishery and shrimping activities will be affected, groundwater table characteristics will be changed, and so on and so forth.

A second group of functions whose importance is often underrated are the extensive exploitation functions: all those practices involving human 'harvesting', but requiring few or no outside inputs. Examples include *extensive forms of herding, traditional paddy farming in wetlands, fishing*, etc., activities widespread in the tropics and with far greater potential than is often appreciated. Floodplains in particular, as producers of high-value protein, should be incorporated in plans more often than is presently the case.

The third group of functions, the intensive exploitation functions, can only find expression after investment of capital, energy and other such inputs. Examples include hydropower generation, irrigated agriculture and water abstraction for industries and towns. The potential of these functions is often overestimated, at the expense of the others. In this area, problems centre around financial profitability, damage to the social environment of local populations, durability and ecological decline.

In order to achieve a better-balanced match during development of a river system's functions and values, planning should take place at the river-basin level. To this end, a number of recommendations and guiding principles are offered (see p. 26). At the core of this planning procedure should be water allocation, based on an analysis of the actual and potential functions of the entire river system, as well as of current bottlenecks in fulfillment of these functions. Due attention should be given in development schemes to such problems as excessive sedimentation, serious water pollution, water shortages in the dry season, and the flooding of towns and villages. Valuable wetlands and productive areas such as spawning grounds for fish must receive protection wherever possible. Alongside rehabilitation and protection, development is also essential of course. Such development should take shape at the regional level, by means of combined land and water management planning, making proper allowance for the carrying capacity of the social and ecological environment. Ensuing interventions should subsequently be assessed by means of an 'environmental impact assessment' procedure. For each class of intervention, the Appendix indicates the impact, risk and mitigating measures or available alternatives.

# 1 INTRODUCTION

With the exception of deserts, tundras and certain other regions having special drainage regimes, every part of the world finds itself in a river basin. In an ecological sense, a river basin can be considered a 'top-to-bottom' gradient in various physical quantities (height, climate, relief, soil composition, vegetation etc.) in which many processes are governed by the water regime. In social terms, too, a river basin exhibits systemic characteristics tied to the river itself, particularly in the Third World (trade routes, patterns of riparian population composition etc.). Consequently, river basins often make very suitable planning units (Hamilton & King, 1984), especially for water-related projects and processes.

For a very long time, rivers have fulfilled a major role in national economies. In North America almost 80% of hydropower potential is currently utilized. In the case of Africa this is only 2.6% (Biswas et al., 1980). The two world rivers with the greatest discharge rate, the Amazon and the Congo, have been commercially exploited to a minor degree only. It is anticipated that in the coming years world irrigation capacity will be utilized at a rapid rate. Projections for the year 2000 indicate that almost twice the amount of water will be used for irrigation as was the case in 1970 (Ambroggi, 1980). There is still clearly a great deal of change in store for the river basins of the Third World. Illustrative in this context are the giant scheme encompassing construction of 8 enormous dams in Brazil, the plans for some 150 dams in the Sahel region and the programme for irrigation and power generation along the River Mekong.

At the same time, the deeply disruptive social and ecological problems resulting from dams constructed in the past are familiar from the now classic examples of - among others - Lake Kariba (River Zambezi), the Aswan Dam (Nile) and the Mahaweli Ganga Scheme (Sri Lanka) (cf. Scudder, 1972; George, 1972; Kassas, 1972; Goldsmith & Hildyard, 1984; Iriyagolle, 1978). Hundreds of thousands of people were compelled to make way for the construction of giant reservoirs, while millions of hectares of land, fertile fields and pastures, tropical rainforests, wetlands and other such areas were inundated for ever. In addition to these spectacular projects, though, countless far smaller developments such as small-scale irrigation dams, canalization schemes and industrial and urban water abstraction will, now and in the future, bring about substantial ecological and social change in the river basins concerned.

This report deals with the environmental consequences of these interventions, discussing potential for ecologically sound development and management of river basins. In this, we restrict ourselves to water management (the river system) and those projects affecting water management. The main focus is thus on the functions and values of the river system as a whole, including related schemes such as dams, irrigation projects, canalization and polder creation.

Chapter 2 provides a general overview of the river system, describing the upper, middle and lower course.

Chapter 3 gives a more detailed description of the values and functions of the river system, discriminating between natural values, spontaneous functions, extensive and intensive exploitation functions and health. Attention is also focussed on the main areas of vulnerability and on environmental problems currently threatening river systems.

Chapters 4 and 5 and the Appendix form a single unit. Chapter 4 describes aspects of river-basin management with reference to the planning process. On the basis of the values and functions discussed in Chapter 3, criteria are also formulated for ecologically sound development and management.

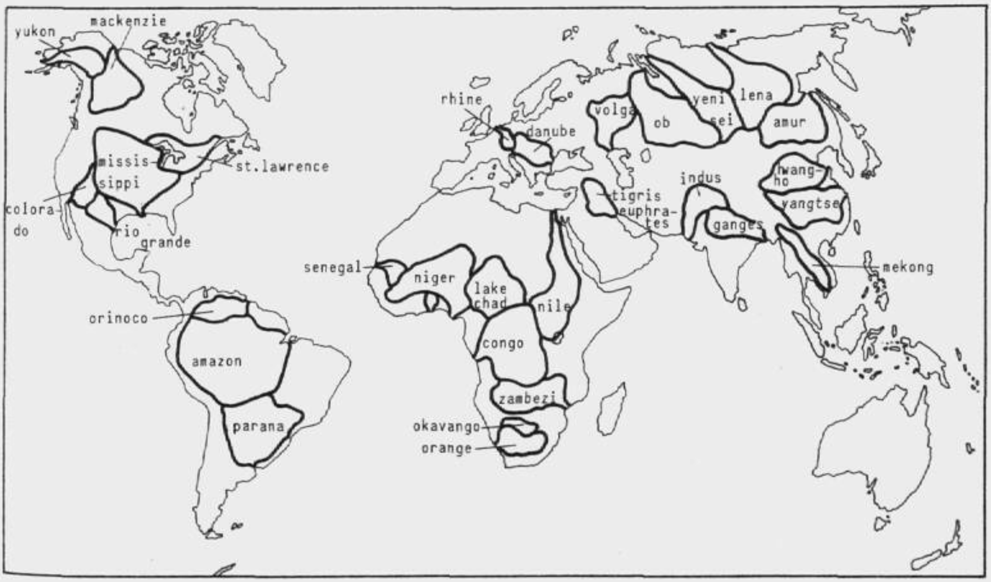
Chapter 5 provides an overall, and more cohesive discussion of the consequences of given interventions. In the Appendix these effects are specified for each intervention.

## 2 WHAT IS A RIVER BASIN?

Rivers form an important link in the earth's hydrologic cycle. Through its erosive action, a river also exerts a considerable influence on the shape of the landscape. Through erosion and sedimentation, material is moved from the river's source down to lower sections of the river basin: the result is a degree of levelling in the lie of the land. However, a lowering of the erosion base (e.g. lowering of sea level) or the presence of soft bedrock may cause the river to cut into the landscape, causing new accentuation of relief (e.g. the Grand Canyon of the Colorado River).

The so-called watershed forms the natural boundary of a river basin. In mountainous regions such a divide can be clearly localized: it runs along the peaks and ridges of the mountains enclosing the catchment area. River basins may be extremely large (that of the River Amazon covers an area of 5.7 million $km^2$), or very small (e.g. the Ruvuma, on the Tanzania-Mozambique border, with a drainage basin of only 54,000 $km^2$). The map of Fig. 2.1 shows the world's major river basins. Fig. 2.2 provides a detailed picture of the river basins of West Africa.

Figure 2.1 The world's major river basins



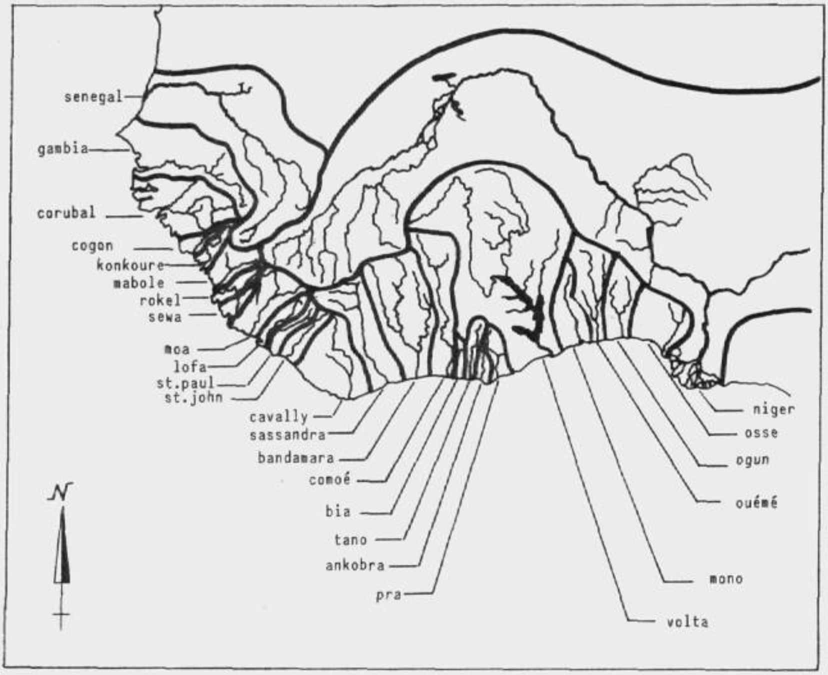



Figure 2.2 Detailed view of the river basins of West Africa

Roughly speaking, a river can be divided into three sections: the upper reaches (source and headwaters), middle reaches and lower reaches (river mouth). A river usually conforms to a concave upward curve (Fig. 2.3), with a steep upstream section (steep gradient) and a slightly sloping downstream section (Zonneveld, 1981). This difference in gradient

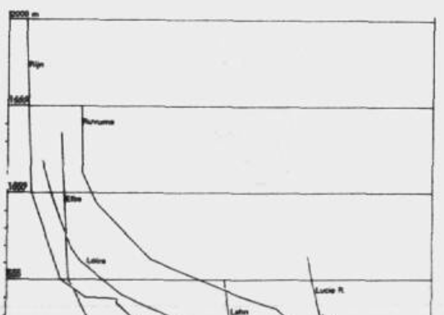



Figure 2.3 Graded profile of several rivers (from: Zonneveld, 1981)

indicates a clear difference between the upper course and the rest of the river. Rivers discharge may be to the ocean (e.g. the Niger), a lake (e.g. the River Chari, flowing into Lake Chad) or an inner delta (e.g. the River Okavanga, which loses its water in the Kalahari Desert). In the case of rivers flowing into the sea, saline incursion (the 'salt tongue' that can intrude as much as several hundred kilometres upstream) plays an important role in the ecology of the river.

## 2.1 Upper reaches (source and headwaters)

The upper course of a river is characterized by a multitude of small streams and rills, frequently with a very steep gradient, which are fed by glacial melt or precipitation resulting from the upward movement of warm air. The fast-flowing water transports a considerable amount of eroded material downstream, where it is deposited on floodplains and in the delta in the form of alluvial sedimentation.

The high streamflow is a key factor in the development of biological organisms. The development of plankton, for instance, is checked because they are continuously being swept downstream. For the number of species of fish, too, the water velocity constitutes a factor of major importance, in addition to temperature. In the upper reaches of the stream we find lower temperatures, higher flow rates and consequently appropriately adapted species which, owing to the extremes of environment, are relatively few in number (Odum, 1971).

The upstream water regime is governed by many factors, the most important of which are rainfall, soil characteristics, vegetation and land use. Soils may be shallow or deep to very deep (tens to hundreds of metres, as is the case with the lava soils of the Kalikonto Basin in Indonesia), and may consist of peat (Kisii Valley, Kenya), lava, clay, sand etc. The steep slopes usually have a tree cover, the root structure of which holds the soil together, with foliage breaking the heavy rains. In this way, erosion and landslides are effectively prevented. On the less steep slopes we find primary or secondary forest, grassland or fields, depending on population pressure. Here, traditional cultures may have been practising shifting cultivation for thousands of years, not necessarily leading to degradation and increasing erosion if cycles are kept sufficiently long (Hamilton & King, 1983). In flat areas and local depressions, we find lakes and marshes. These are usually smaller and are of less regional importance than those in the middle reaches of the river.

## 2.2 Middle reaches

The middle course of a river is characterized by a clearly discernible main river stem, a relatively gradual channel slope and the absence of marine influences. When flowing through comparatively flat land, the middle reach of a river is almost always surrounded by a floodplain. This can be explained by the large seasonal difference in discharge. In times of high discharge the river overflows its banks and inundates the surrounding area, the floodplain. If a river has only a very shallow profile (such as on the Kafue Flats in Zambia, where the river level drops by only several metres over a distance of 240 km) vast areas may be submerged. In its middle course, the River Rhine first has a floodplain (the 'Upper Rhine'), which narrows substantially (e.g. at Lorelei) as the river passes through hilly countryside.

In the tropics, floodplains are often still in their natural state. The high peak discharges occurring in the wet season inundate approx. 300,000 km² of land in Africa, for a period of several weeks or even months. In South America and Asia, too, hundreds of thousands of square kilometres are flooded each year (cf. Table 2.1). In Bangladesh alone, for example, flooding affects an area of 93,000 km². Because of the vastness of these areas and the enormous influence these floods have on man and his natural environment, floodplains constitute one of the most important ecosystems to be found in a river's course.

| AFRICA: | | ASIA: | | LATIN AMERICA: | |
|---|---|---|---|---|---|
| Senegal | 13,000 | Euphrates-Tigris | 20,000 | Magdalena | 20,000 |
| Niger | 76,000 | Indus | ? | Paraguay | 90,000 |
| Volta | 9,000 | Ganges | 24,000 | Orinoco | 90,000 |
| Chad Bas. | 63,000 | Ganges-Brahmaputra | 93,000 | Amazon | >100,000 |
| Zambezi | 15,000 | Irrawaddy | 31,000 | | ------- |
| Congo | ? | Chao-Phrya | ? | | 300,000 |
| Okavango | 17,000 | Mekong | 53,000 | | |
| Nile | 92,000 | | ------- | | |
| | ------- | | 221,000 | | |
| | 285,000 | | | | |

Table 2.1 Major floodplains in the Third World (area in km²)
(From: Welcomme, 1979)

Because the river current slows down considerably outside its original bed, fertile sediment is deposited on the plains, forming clay soils. Primary production in such regions is frequently very high as a consequence of these alluvial deposits, combined with optimum conditions for plant growth (mainly gramineae), algae and plankton. This in turn forms the basis for a rich community of fish, fowl and game. Man also benefits from these conditions, by way of fishery, herding, hunting and the cultivation of rice and other crops.

Within the river basin, floodplains must be counted among the most productive fishing areas and herding grounds for the local population. In part, this is due to their multi-functionality: fishing is rewarding and cattle can graze, and both rice and sorghum can be cultivated, as long as the population allows for the seasonal fluctuations in water level.

Lakes and swamps are considerably less dynamic than rivers and flood plains. The streamflow is far slower, enabling relatively stable aquatic ecosystems to develop. In shallow lakes there is often distinct zone formation, from the perimeter to the centre. Succession frequently sets in: through this process a lake with border vegetation changes into heavily vegetated swampland, with swamp forest eventually developing in some cases. Often the border zone forming the transition between thick vegetation (e.g. papyrus) and open water contains the greatest number of species. Here, many organisms find shelter from predators, as well as food and sufficient oxygen to survive. Over large areas of these swamps there is insufficient light under the water surface, resulting in oxygen deficiency or even a complete lack of oxygen.

Deeper lakes are often characterized by vertical zoning. As a result of stratification, i.e. the formation of water layers differing in temperature, specific mass and oxygen content, biological life is concentrated mainly in the upper layer. Descending into deeper levels, less light becomes available for photosynthesis. Oxygen production therefore decreases, while the oxygen demand increases because of the amount of dead organic matter sinking to the bottom. In deeper strata, therefore, zero-oxygen conditions may arise. The influence of the wind on this stratification may be extremely great. With the advent of the wet season, storms may set the entire body of water in a lake in motion, effecting homogeneous mixing. This brings non-oxygenated and $H_2S$-rich water to the surface, which may cause sudden fish kill. It has been calculated that in Lake George (Uganda) more than one million fish must have been killed in the space of several hours through oxygen deficiency after the water had been violently mixed by a storm. On the other hand, such mixing returns valuable nutrients from the lake bottom to the upper layer, stimulating primary production. These processes of stratification and mixing can exhibit a diurnal as well as a seasonal cycle, which may be subject to disturbance from sudden local storms.

## 2.3 Lower reaches (river mouth)

As the river approaches the mouth, its fresh water mixes with the saline water of the sea. As a consequence, and because of the slower currents prevailing here, a large proportion of the silt settles to create a delta or other river-mouth formation, depending on ocean currents along the coast, the type of sediments carried by the river and such factors. Sometimes the mouth is extremely broad and exhibits a distinct saltwater/freshwater gradient; we then speak of an estuary. In the tropics we often find mangrove forests in such areas, forests that require the influence of the sea as well as the infiltration of fresh water. There are some 60 tree species in the world that are to be found exclusively in such mangroves. They set specific demands on their habitat, including the aforementioned salt gradient and periodical flooding. These forests constitute rich ecosystems and form major nurseries for shrimps and fish (Saenger et al. 1983).

Estuaries are 'sinks' for all kinds of inorganic and organic matter. They are consequently extremely productive and of major importance for fisheries, including those of the open sea: in many cases, the fish caught in the oceans have grown to maturity in estuaries and other shallow coastal waters. In addition, the sediment carried by the river may form the basis for large fish populations further offshore (e.g. the sardine fishery in the Mediterranean near the Nile Delta, before construction of the Aswan High Dam).

Although not always strictly connected with the river system, coral riffs, tidal marshes and mudflats should also be mentioned here, for some of these lie so close to a river mouth that they are strongly influenced by the discharge regime. Under the influence of freshwater, interesting brackish-water vegetations may develop in tidal marshes and mudflats in the vicinity of the river mouth. For wildfowl, particularly, these ecosystems are of exceptional importance. Because of an increased supply of sediment due to upstream erosion and also because of environmental contaminants, coral riffs are presently under an increasing threat.

Coastal soils vary from peat to clay or sand. The clay soils on which mangroves grow may contain considerable levels of pyrite, resulting in extremely acid soils ('cat clay') if drainage operations are undertaken.

## 3 FUNCTIONS, VALUES AND AREAS OF VULNERABILITY OF THE RIVER ECOSYSTEM

For mankind, the significance of a river is very differentiated and may also vary from era to era. Identification of a river's functions for man is subject to differences of interpretation among cultures and individuals. In order to arrive at a conceptually sound and at the same time comprehensive organizational division of these functions, the following approach has been adopted: a division into functions and values, with a further tripartite subdivision of the functions (cf. De Groot & Van Tilburg, 1985). Where we are concerned with the utility value of the river for man, we refer to 'functions'. In principle, these can be expressed in terms of prosperity, although for many spontaneous functions, e.g. aesthetic and cultural, a quantitative epithet is hardly feasible.

In addition, we also refer to the (intrinsic) natural values of a river. In the present context we shall restrict ourselves to the natural values, as usually defined in present-day international conservation circles.

Finally, we discuss the areas of vulnerability of a river system, with reference to Fig. 3.3., shedding light on the relationships between disturbance of functions upstream and the consequences appearing downstream.

### 3.1 Natural values

Within a river basin a number of types of ecosystem are to be found that are directly dependent upon the stream. As we move downstream, we may encounter lakes, marshes and floodplains, and the river's banks may be covered by so-called riparian woods, changing to mangrove forests as we reach the river mouth.

There exist a number of accepted criteria with which to determine the conservation value of these ecosystems:

- The rarity of elements of the ecosystem (e.g. species) or of the type of ecosystem as whole. Mangroves, for instance, have declined in area so much worldwide that each and every mangrove area must be considered very valuable (Saenger et al., 1983). For lakes, on the other hand, this does not hold; their value depends on whether they form a refuge for rare biological communities or species.

  In the case of mangroves, a list has been drawn up of 20 plant and 89 animal species that, to a greater or lesser degree, are dependent on the mangrove habitat and are presently threatened in their continued existence in one or more countries (Saenger et al., 1983). A vivid example is the Bengal tiger, which is now restricted to the extensive Sundarbans mangrove reserve in Bangladesh and India. Other examples of rare, specifically wetland-dependent threatened species include the manatee, in the mouths of African rivers; the Kafue lechwe, a species of marsh antelope, which is now found only on the Kafue Flats of Zambia; and the shoebill, related to the stork, resident in the Sudd marshes of the Nile valley.

- The degree of virginity. Ever more areas have become subject to human influences, thus losing their 'virginity'. Agricultural development, in particular, has drastically changed the face of the natural landscape; many areas are consequently referred to as 'semi-natural landscapes'. It might be added that many of these areas are richer than they were in their original, natural state, as a result of the ecological gradients created by man.

  A case in point is a particular type of valley landscape found in the Dutch provinces of Overijssel and Drenthe ('essen-beekdalenlandschap'), created in former centuries by human action. By keeping flocks of sheep on the heaths, using sheep dung and heath turf on the arable land round the farmsteads and raising cattle on the moist valley soil, a nutrient gradient was created, increasing from the oligotrophic (nutrient-poor) heathland down to the low-lying areas and leading to a great diversity of habitats and biological communities.

- The degree of diversity. For many systems it holds that the greater the diversity, the greater their value (more species means more complex relationships and therefore a greater chance of unique types of community). This does not apply, however, to oligotrophic and hypersaline conditions, where the extreme physical conditions allow for only a limited number of species, which are often biological rarities, moreover. It is therefore preferable to refer to the diversity of the characteristic species for these environments, which may in such situations of species poverty - in absolute terms - still be high. Even under conditions where the high dynamic guarantees a (relatively species-poor) pioneer vegetation, the natural value may be greater than anticipated purely on the basis of the diversity criterion (Morgan, 1977).

  The floodplains are a good example in this respect, exhibiting a powerful dynamic as a result of periodic inundation, through grazing by cattle and wild herbivores, and through periodic grass-burning. This ensures the continued existence of grassland, which is rejuvenated each year anew. A number of organisms have succeeded in adapting well to this dynamic environment, e.g. the aforementioned Kafue lechwe, which can graze below the water surface, and the lungfish, which can survive periodic drying-up of its aquatic environment by digging itself into the mud and absorbing oxygen from the air.

- Potential value. Sometimes a natural area may in itself have little value, but may (re)blossom, as it were, through external action (e.g. artificial inundation or conservation-oriented management). The cost of such an intervention is of paramount importance: the potential value of a particular area may be termed high only if a valuable natural habitat may be created at reasonable expense.

  By means of relatively simple modifications in water management, arid lands can sometimes be transformed into wetlands with a high natural value. A good example is the 'Bird Paradise' Keo Ladeo near the town of Bharatpur in northern India. Once an arid savanna, it was changed into a flourishing marshland reserve by diverting part of a nearby river.

Special mention should be made of the criterion of the international importance of wetlands in river basins. A fair number of tropical mangroves, swamps and floodplains function as winter foraging grounds for millions of migratory birds from northern latitudes (see Fig. 3.1). This fact has led the International Convention on Wetlands of International Importance especially as Waterfowl Habitat (the '*Ramsar Convention*') *to* formulate the 1% norm for the significance of wetlands for birds ("A wetland is of international importance if it regularly supports 1% (being at least 100 individuals) of the flyway or biogeographical population of one species of waterfowl").

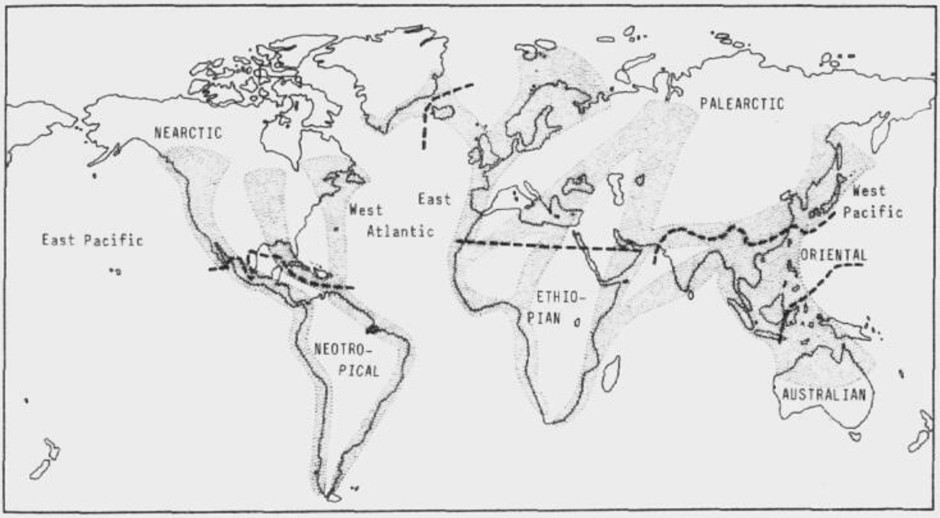



Figure 3.1 Wildfowl migratory routes in various regions of the world (From: NOME, 1982)

## 3.2 Spontaneous functions

The drainage basin of a river fulfils a series of functions for man that require no human intervention, i.e. with no need of investments or regulatory systems. Although the importance of a well-functioning ecosystem cannot always be characterized in an exclusively quantitative sense, there follow a number of aspects that may be classed as spontaneous functions.

Rivers constitute a major source of genetic material, in the form of a multitude of aquatic and semi-aquatic organisms. It has, for instance, been estimated that the Amazon supports more than 1000 species of fish. In general, it can be stated that the longer a river system, the greater the number of species it will harbour (Welcomme, 1979). River systems form a genetic store not only for economically important fisheries, but also for agricultural crop species. For paddy rice cultivation, for instance, it is essential that wild varieties of rice, e.g. those found in mangroves, be protected in order to preserve healthy strains of this major cereal.

Particularly in slow-flowing or stagnant bodies of water (e.g. in wetlands) an abundance of biological forms are to be found: plankton, macroflora (higher plants), invertebrates, fish, reptiles, amphibians, birds and mammals. On the Kafue Flats of Zambia more than 400 species of wildfowl have been documented, and some 22 species of ungulata (hoofed mammals) are supported. It is clear that this wealth of genetic resources also has a high natural value (cf. Para. 3.1).

Although there is still only sparse knowledge of the species abundance of aquatic invertebrates such as insects, shellfish and crustaceans (of the 46 groups of aquatic invertebrates found in Africa, only 7 have been the subject of in-depth taxonomic study (Davis & Hart, 1981)), we may safely assume that it is quite substantial. The limited knowledge we have of these biological resources makes it difficult to make an accurate assessment of the utility value of this genetic reservoir. Apart from the evident importance of certain economically valuable species groups such as fish, crustaceans etc., though, it should be borne in mind that a rich genetic reservoir is also extremely valuable in evolutionary terms. It forms the basis for evolutionary adaptation to changing conditions in the physical environment. This is of major importance for a stable environment and for the potential of food crops, medicinal herbs and suchlike for future generations.

### Regulation of the water regime

The buffer action of wetlands (floodplains, marshes etc.) in a river basin serves to reduce the usually strong fluctuations in river discharge. It has thus been discovered that the peak discharges of rivers in Wisconsin (U.S.) are far higher in the case of river basins poor in wetlands than for those with abundant wetlands. Basins lacking wetlands have a discharge rate five times higher than those with 40% wetlands, for the same surface area (Noble & Wolff, 1984). Alongside this 'sponge' effect, this is of course also due to greater evaporation rates.

Obviously, the natural water regime will not always be optimally attuned to human requirements. When intervening at a given location, however, care should be taken not to completely destroy the regulatory function of other areas of the basin. Local 'gains' may eventually yield a loss for the overall regime. A proper assessment of this function is a precondition for sound river-basin management.

### Regulation of erosion and sedimentation

Although erosion is nowadays often discussed in a negative sense, it should be remembered that it is in principle a natural phenomenon. A large proportion of the land on which human settlements have evolved was created through the erosion of mountains, followed by river transport and finally sedimentation in floodplains and deltas. The fertility of these areas is extremely high. Many tons of silt are deposited per hectare (varying from 40 to 100 metric tons per annum), effectively achieving fertilization with nitrogen, phosphate and valuable trace elements to an amount of several hundred kilograms per hectare per annum. Construction of the Aswan Dam has resulted in a drastic decline in alluvial deposits in the delta and floodplains of the Nile, compelling Egypt to import extra artificial fertilizers to the tune of 100 million dollars annually *(Goldsmith and Hildyard, 1984)*.

Dams capture a large percentage of a river's silt load, which is detrimental both for downstream agriculture (reduced soil fertility) and for the dam itself (reduced reservoir capacity).

These processes are also disrupted by accelerated erosion in the upstream section of a river. An increase in silt load causes the river bed to rise relative to the surrounding land, making fatal floods an ever more likely occurrence. The high-water levels of the River Brahmaputra have risen by some 2 metres over the last 70 years (Fig. 3.2).

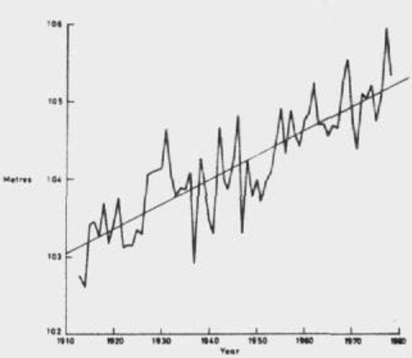



Figure 3.2 Annual peak discharge levels of the Brahmaputra
(From: Abernethy, 1980)

The role played by forests in the regulation of water discharge is often inaccurately interpreted. The woodlands and forests of steep slopes are virtually irreplaceable as a means of preventing erosion and degradation. For the more gradual slopes, this function can in principle be fulfilled by either primary or secondary forest, or by grassland vegetations and small-scale arable plots. In this respect, grassland has the added advantage of providing soil protection that is just as efficient as that achieved by tree cover, but without the large evaporation losses associated with the latter. For these more gently sloping areas, deforestation is not in itself usually the cause of increased erosion, reduced water buffering capacity and the consequent derangement of the water regime. However, a different situation arises if deforestation is followed by livestock and cultivation systems that lead to overgrazing, too short rotation periods and so on. If forestry, agriculture and livestock management are not moulded to the specific characteristics of soil and slope, i.e. if they are not founded on sound watershed management, a process will be instigated that will irrevocably lead to soils being washed away and the spontaneous functions of the downstream reaches of the river being seriously disrupted (Hamilton & King, 1983).

### Influence on climate

The characteristics of the hydrologic balance in a watershed (precipitation, evaporation, transport and buffering) exert a major regulatory influence on climate. Water surfaces generally have a damping effect on strong fluctuations of temperature and create a higher degree of humidity in the surrounding area.

### Water purification

The purifying capacity of rivers, wetlands and lakes, finally, may also be termed a spontaneous function. This purification function relates mainly to water containing organic waste (sewage water) and nutrient-rich drainage water with high phosphate and nitrate levels. It has been calculated that in the United States one hectare of marshland achieves approx. $ 35,000 worth of tertiary purification (reduction of the phosphate load) per year (Gosselink et al., 1974). Artificial wetlands have even been created for treating domestic wastewater (as a rule of thumb, approx. 150 $m^2$ of reedbeds are required for every 4 population equivalents (Sloey, 1978)). Papyrus marshes also have a great purifying capacity, a quality frequently utilized, e.g. in Kenya where the wastewater of the towns and villages on the banks of Lake Victoria is recycled through the papyrus marshes adjacent to the lake.

## 3.3 Extensive exploitation functions

The term 'extensive exploitation functions' covers those functions of the natural ecosystem which, while requiring 'harvesting action', presuppose virtually nothing else besides the input of human labour. What is involved is the harvesting of natural produce without this necessitating any returns to nature. In the process, the natural ecosystem is modified (e.g. fishery activities will modify fish populations in terms of species composition and age distribution) but not completely transformed into a single-product monoculture. A characteristic feature of extensive exploitation functions is that it is often possible to support several of them simultaneously (multi-functionality).

Fisheries constitute one of the major extensive exploitation functions of river basins. In Africa catches of fish account for approx. 40% of the total protein requirement of the rural population (Awachie, 1981). The total world freshwater fish catch is estimated at some 10 million tonnes (FAO, 1976: in Welcomme, 1979), a major proportion coming from rivers and floodplains.

Extensive forms of livestock management, too, are often dependent upon the natural resources available in river basins. The floodplains, in particular - which cover an area of about 300,000 $km^2$ in Africa - form important grazing lands for semi-nomadic herds. On the inner delta of the Niger in Mali, for example, more than 1 million head of cattle graze each year in the arid season. If it were not for annual inundation, the same area could support only 60,000 cattle (Drijver & Marchand, 1985). The floodplains thus form an indispensable link in the livestock farming of a region far greater than the floodplains themselves.

A third form of exploitation is floating rice culture and recession culture. On floodplains and along the shallow banks of lakes, rice is planted before the water level begins to rise (so-called floating rice). Dry crops such as sorghum and millet are planted right at the end of the flooding period, as the soil falls dry while still retaining a lot of moisture.

Traditional irrigation systems, characterized by small-scale, communally managed works (dikes, channels etc.) such as were formerly found in the Nile Valley and are still to be seen in the Tana Delta of Kenya, can usually be classed as extensive exploitation functions, because the input of capital and agrochemicals is still frequently negligible. This is mainly due to the massive amount of human energy devoted to such projects (weeding, ditch digging etc.).

Other traditional forms of exploitation include the hunting of wild game (e.g. ungulates) and wildfowl, and the gathering of forest produce from mangroves and floodplain forests.

Finally, there is transportation, which is often utilized as an extensive exploitation function. The main requirement is an appropriate level of water in the river, while excessive aquatic plant growth can pose serious problems (floating papyrus islands, among other phenomena, may block waterways entirely).

## 3.4 Intensive exploitation functions

All those functions that can be materialized only by means of major inputs of capital, fertilizers, pesticides and/or energy are termed intensive exploitation functions. The following 'law' appears to be characteristic of these functions: if one of the functions is actually realized, the capacity to implement any of the other functions is seriously reduced. In other words, maximalization of an intensive exploitation function usually soon leads to monofunctionality.

We are concerned with the following activities:

- intensive, irrigated agriculture, employing irrigation water from a river or reservoir. This category of exploitation is characterized by the large scale on which cultivation takes place, by monocultures, necessitating the use of pesticides, and by several harvests per year, which can only be achieved with the help of fertilizer inputs.

- power generation ('white coal'), by means of hydroelectric dams.

- intensive transportation: by means of canalization and the construction of sluices and dams, a river can be redesigned to carry inland shipping (cf. the Rhine).

- industrial and drinking water supplies: industries often require large amounts of process and cooling water, subsequently returning it to the river chemically and thermally polluted. Towns and cities, too, may constitute large-scale consumers of riverwater. Lac de Guiers, in Senegal, serves as the source of potable water for Dakar, 300 km to the south. The lake is fed by the River Senegal via a canal. In the last few, dry years an earthen dam in the main stream has been employed to achieve a regular and adequate water supply to the lake, guaranteeing secure drinking water supplies (and irrigation of sugar-cane plantations).

## 3.5 Health

Although a healthy environment (and sometimes: a threatening environment) can be viewed as a spontaneous function of a river basin (clean air, clean water, but also: parasites), health is here treated separately because of the many complex relationships it may exhibit with other functions. Health is governed by human resistance, mental and spiritual as well as physical. In this respect, an adequate and varied diet (exploitation function!) and pure drinking water are essential preconditions.

At the same time, good health is governed by the biotic environment surrounding man. Insects, bacteria, slugs, rat plagues and so on may constitute a direct or indirect threat to public health. The prevention of waterborne diseases such as malaria and bilharzia is closely tied up with the presence of stagnant or sluggish watercourses. Fast-flowing water, on the other hand, may cause river blindness (onchocerciasis).

## 3.6 Areas of vulnerability

It is difficult to generalize about the environmental problems confronting river basins in the tropics today, because of substantial local and regional differences. It is nevertheless possible to indicate some of the major areas of vulnerability and the bottlenecks commonly encountered. As a starting point, we take the functions discussed in Para. 3.2 to 3.4, since these describe exactly the dependence existing between man and a river. Problems may arise within this relation when, for instance, the spontaneous functions are disturbed by increasing erosion, or when the intensive exploitation functions are not durable.

The greatest risks with which we must reckon when considering many tropical rivers today can be classed in 4 categories. In many cases we see a spatial relation between intervention and effect, an intervention upstream causing problems downstream.

### Erosion

In the upper reaches of many rivers, erosion is taking place at an accelerated rate. The causes are deforestation and inappropriate land use on the upstream hillsides. In the middle section of the stream, these practices may lead to flooding (through raising the river bed relative to the surrounding land) and silting up of reservoirs, canals and irrigation works. At the river mouth, an elevated alluvial load causes the destruction of vulnerable ecosystems, such as coral riffs. The denuded slopes in the uplands dislocate the hydrologic regime as the sponge effect of the soil and vegetation is lost. As a consequence, there are higher peak discharges in the wet season and lower river levels in the dry season. This induces flooding and saltwater incursion, which is detrimental to agriculture and to the mangroves swamps.

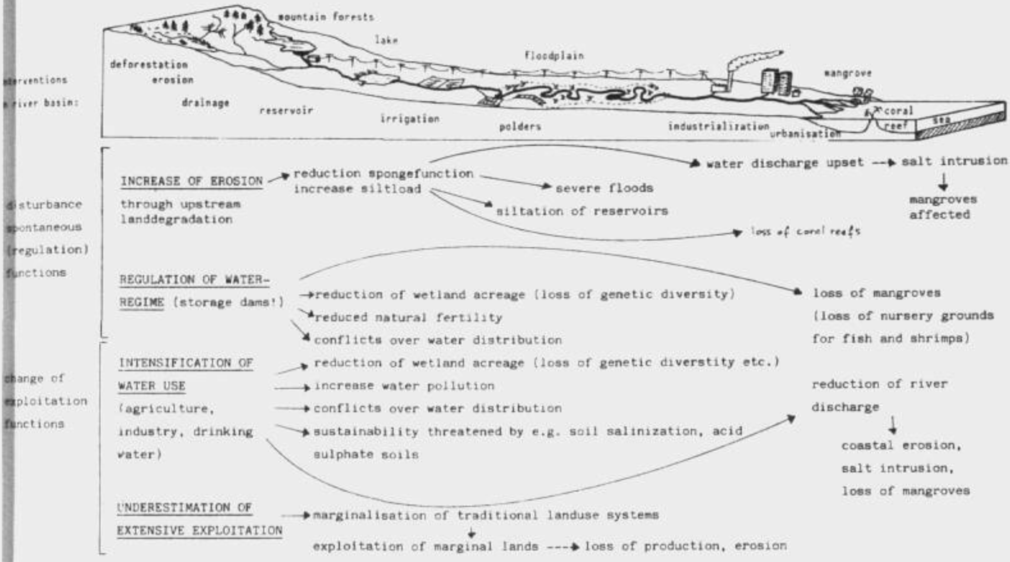



Figure 3.3 Risks and areas of vulnerability of the river system

## Regulation

On just about every tropical river today, activities take place whose aim is to regulate the river regime (e.g. by construction of dams, dikes and canals). Apart from such benefits as power generation, buffering of water for irrigation purposes, improved navigability etc., such engineering works also entail risks. In many cases river regulation will lead to reduced inundation of floodplains and marshes, resulting both in a loss of natural values and genetic diversity and in a reduction of the natural fertility of the valley (reduced alluvial deposits). In addition, conflicts are to be anticipated about the availability of water for the various groups of consumers: now that it has become possible, in principle, to regulate river flow, distribution no longer simply follows from the natural water regime, thus becoming a subject of social and political debate.

## Intensification of water use

Such conflicts may also be engendered through intensification of water use, for reasons pertaining not only to water quantity and timing, but also to water quality. Agricultural, industrial and domestic users return wastewater that is frequently deleterious to existing wetland ecosystems, human consumption and fisheries. In the longer term, there is the risk of a decline in yields, owing to the fact that intensive systems of exploitation are often not durable in character. The frequently high investments made in irrigation systems make short-term profits more important than long-term harvest security. Excessive silting and deterioration of soil fertility has already affected millions of hectares of agricultural land (cf. Pakistan). Along coasts, unanticipated effects may occur, with reduced discharge levels resulting in shoreline erosion and saltwater incursion (cf. Nile Delta).

Underrating of extensive exploitation

This fourth category concerns a neglect of activities, potentially leading to serious environmental problems. As a result both of autonomous processes (population growth for instance) and of inadequate allowance being made in planning procedures for the means of subsistence of traditional fishermen, pastoralists and farmers, these groups may be pushed into a marginal position. This may in turn lead to overexploitation of resources or exploitation in places with a high natural value. Here, too, water distribution often lies at the root of the problem. Optimization that does take into account the requirements of man and nature is essential if problems are to be resolved, though on its own this is often no more than a first step. Reduced population growth, alternative employment, intensification of fisheries and other development opportunities are just as important. In the following chapter, we shall consider these issues within the broader context of river-basin management.

# 4 RIVER-BASIN MANAGEMENT

## 4.1 Analysis of water use at the river basin level

The development and management of an entire river basin will usually take place at the national level or, if the river traverses several different countries, at the international level. As we shall see below, this makes substantial demands on the administrative and institutional organization of the country or countries concerned. A planning procedure that attaches appropriate significance to the ecological boundary conditions set by a river basin must, in its system of objectives, be broad and integrated in character (cf. the 'Integrated River-basin Development' concept, as elaborated by O'Riordian & More, 1969).

In the first place, there must be a proper understanding of water consumption (the production functions): what sectors use water, on what occasions, and what is the quality of any recycled water? Agriculture, industry and households constitute major consumers of water, at the same time returning water of such poor quality that is can scarcely be consumed by other users. Other sectors, such as electrical power generation, shipping and fisheries, do not consume water, but do impose demands on the quantity of water in the river system. Water levels may not sink too low, there must be sufficient water at the right time to inundate fishing grounds on floodplains each year, and so on. If the river is characterized by a seasonal water regime, with high streamflow following the wet season and markedly lower discharges in the arid season, it is advisable to to determine total consumption requirements for each individual sector for the dry, critical period.

An analysis should also be made of the spontaneous functions and values of the river. Which spontaneous functions fulfilled by the river at the moment are sufficiently important to be preserved? Pertinent examples include prevention of saltwater incursion, regulation of the overall watershed regime (throughput of heavy rains, for instance), climatic regulation and sedimentation of fertile silt. In some cases, there may be bottlenecks with respect to human settlements (cf. Para. 3.6), such as the regular occurrence of heavy flooding in densely populated areas, or pronounced saline intrusion during periods of low discharge. This will often be caused by the disappearance of the buffer capacity of the headwaters. Widescale deforestation upstream frequently results in increased erosion, causing a rapid elevation of the river bed. A decline in the natural floodplain area through impoldering may also lead to unacceptably high water levels in the wet season, through a reduction in the overall buffer capacity of the river system.

## 4.2 Planning at the river-basin level

The above analysis of bottlenecks should form the basis for planning improved watershed management, with the functions and values of importance for human habitation being rehabilitated or optimized. Such plans should include guidelines for forestry and agriculture in those areas vulnerable to erosion.

The 'demand-side' analysis must be combined with dry-season water supply, an exercise that will usually reveal a number of conflicts between the various functions fulfilled by the available water. These may be resolved by:

1) increasing the supply of water in the dry season, or ensuring a better spread in time;
2) assigning priorities.

Re 1) A frequent approach is to construct a dam, by means of which water can be buffered for continued availability in the arid season, at the same time providing power-generation capacity. It should be noted that this is at the expense of water flow in the wet season, while these periods of elevated discharge in fact serve an important purpose, in particular for floodplains where pastoralists, farmers and fishermen are dependent upon annual inundation. Dam construction thus implies a setting of priorities to the disadvantage of these functions, while favouring electrical power generation and e.g. irrigation.

Re 2) In order to set priorities, it is obviously essential to make a thorough analysis of the various water consumers involved, giving proper weight to their relative importance. Although, in the final count, this is a political decision, within the scope of given policy objectives it is perfectly feasible to employ formalized multi-criterion analyses for comparing various alternative scenarios. With respect to the objective 'raising food production', for example, it is possible to obtain an indication of the optimum production method, yielding a high output per litre water, as well as providing a balanced and varied diet, guaranteeing social justice and remaining financially viable. The option 'irrigated agriculture' can be compared with production from a floodplain, if expenses and revenues are calculated per unit water. In such a case the picture usually obtained is one in which irrigated culture - provided reasonably efficient water use is achieved - yields a large amount of (high-calory) staple foods at the expense of (very) high financial investments, dependence on foreign know-how and socially and ecologically disruptive changes. The floodplain is characterized by lower, but more varied production of both calories and protein (fish!), a high rate of water consumption, minimal financial inputs and social and ecological stability (cf. the example of the River Niger at the end of the present chapter).

In the same way a critical analysis can be made of the most desirable options for achieving the objective 'electrical power generation'. In this respect, hydropower is but one of the options available. Equal consideration should be given to other possibilities, such as coal-fired power stations, wind power and solar energy. In addition to financial feasibility and technical know-how, an important criterion will be the degree of decentralization of the energy supply. In developing countries the infrastructure for electrical distribution often forms a bottleneck, especially in the case of rural supplies. Small-scale, decentralized power generation by means of wind turbines or solar installations therefore represents an important option for the future.

A river is often the lifeblood of a nation. A good example is the Nile, flowing for the greater part through a desert and on which millions of people in Ethiopia, Sudan and Egypt are dependent for their livelihood. Those living downstream are obviously dependent upon water management upstream. The kind of choices described above must therefore be made in a process of negotiation at the national and supranational level. To coordinate this process, a special 'River Basin Authority' is required. Examples of such a body include the OMVS (Organisation pour la Mise en

Valeur du Fleuve Senegal), in which Senegal, Mauritania and Mali participate, the Tennessee Valley River Authority in the United States and the Niger Basin Authority, in which 9 nations cooperate (Mali, Niger, Nigeria, Chad, Benin, Cameroon, Ivory Coast and Burkina Faso). (Cf. Table 4.1.)

| Basin (and/or project) | Organisation | Sign | Countries concerned | Date of agreement |
|---|---|---|---|---|
| Senegal | Organisation pour la mise en valeur du fleuve Senegal | OMVS | Mali, Mauretania, Senegal | 11-5-'72 |
| Gambia | Organisation pour la mise en valeur du fleuve Gambie | OMVG | Gambia,Senegal | 19-4-'67 |
| Niger | Commision du Fleuve Niger | | Benin, Cameroon, Chad, Guinee, Ivory coast, Mali Niger, Nigeria, Burkina Faso | 26-10-63 |
| Lake Chad | Commission du Bassin du lac Chad | | Cameroon, Niger, Nigeria, Chad | 22-5-'64 |
| Kagera | Organisatin for the Management and Development of the Kagera River Basin | | Tanzania, Rwanda, Burundi | 24-8-'77 |
| Mano | Mano River Union | | Liberia, Sierra Leone | 3-10-'73 |
| Nile | Permanent Joint Commission for Nile Waters | | Egypt, Sudan | 8-11-'59 |
| Plata | Comite Intergubernamental Coordinador de los Paises de la Cuenca del Plata | CIC | Argentina, Bolivia, Brasil, Paraguay,Urugay | 23-4-'69 |
| Plata-Parana (Itaipu) | Itaipu | | Brasil, Paraguay | 26-4-'73 |
| Plata-Parana | Comision Tecnica Mixte Argentino-Paraguaya del Rio Parana | COMIP | Argentina, Paraguay | 16-6-'71 |
| Plata-Parana | Ente Binacional Yacireta | EBY | Argentina, Paraguay | 23-1-'58 |
| Plata-Uruguay (Salto Grande) | Comision Tecnica Mixta del Salto Grande | CTM | Argentina, Paraguay | 30-12-'46 |
| Plata-Uruguay | Comision Administradora del Rio Urugay | CARU | Argentina, Urugay | 7-4-'61 |
| Puyango-Tumbes | Comision Mixta Peruano-Equatoriana para el aprovechamiento de las cuencas hydrograficas binacionales Puyango-Tumbes y Catamayo-Chira | | Equador, Peru | 27-9-'71 |
| All watercourses near border | Comision Internacional de Limites y Aguas | | Guatemala, Mexico | 21-12-'61 |

Table 4.1 International river-basin cooperation (From: Cano, 1983)

In many instances, for example the OVMS and the Preparatory Commission for the Volta Project, such authorities are created at the same time as plans are being developed for large-scale intervention in the river system. At this stage an extensive, integrated study of all the relevant aspects and anticipated side-effects is required, something that can only be properly conducted by a body not bound to (physically irrelevant) administrative regional or national boundaries. In many cases, though, appropriate insitutions are unfortunately lacking, particularly in cases where it is deemed that coordination is unnecessary owing to the absence of a large-scale project - while it has become strikingly manifest that a multitude of smaller projects and activities produce cumulative effects, making integrated watershed management essential.

| Basin (and/or project) | Organisation | Sign | Countries concerned | Date of agreement |
|---|---|---|---|---|
| All water-courses near border | Comision Internacional de Limites y Aguas | IBWC | Mexico, U.S.A | 1-3-1889 |
| All water-courses near border | International Joint Commission | IJC | Canada, U.S.A. | 11-1-1909 |
| Lower-Mekong | Comite pour la Coordination des Etudes sur le Bassin inferieur du Mekong | | Laos, Thailand, Vietnam | 31-10-'57 |
| Indus | Permanent Indus Commission | | India, Pakistan | 19-9-'60 |
| All water-courses near border | Indo-Bangladesh Joint Rivers Commission | | India, Bangladesh | 24-11-'72 |
| Ganges | Mixed Commission for the Ganges downstream of Farakka | | India, Bangladesh | 5-11-'77 |
| Rhine | Commission centrale pour la navigation du Rhin | | Belgium, France, Netherlands, Germany, Switserland, UK | 17-10-1868 |
| Rhine | Commission internationale pour la protection du Rhin contre la pollution | | Germany, France, Luxembourg, Netherlands, EEC | 29-4-'63 |
| Danube | Commission du Danube | | Austria, Bulgaria, Hungary, Roumania, Tchechoslovakia, Ukraine, USSR, Yougoslavia | 18-8-'48 |
| All water-courses near border | Finnish-Swedish Frontier Rivers Commission | | Finland, Sweden | 16-9-'71 |
| All water-courses near border | Comision Hispano-Portugesa para la Reglementacion del Uso y Desarrollo de las Aguas Fronterizas sobre los Tramos Comunes a los dos paises | | Spain, Portugal | 11-8-'27 |
| Vardar-Axios | Joint Greek-Yugoslav Commission for the development of the Vardar-Axios | | Greek, Yugoslavia | 18-6-'59 |

Table 4.1 (cont'd)

## 4.3 Land-use and water-resource planning at the regional level

At the regional level, we are concerned not only with the distribution of water from a river but also with the use of the surrounding land. At this level it is possible to achieve a high degree of integration between land-use and water-resource planning.

One handicap in this respect is the spatially diffuse character of water use. It is not always a simple matter to identify where, and by whom, water is used, and in what quantities. Exploitation of lakes, floodplains and rivers often exhibits temporal dependence and a high degree of integration, and is consequently not easy to represent on a map. Fishery activities shift with seasons, periodically exposed land is cultivated or grazed, water-based transportation is seasonal, canals and ditches are employed to carry water to areas distant from the actual river course, for use in irrigation or for human drinking-water supplies, and so on. At the same time, this multi-functional character is one of the key features of a river system. Local populations have learnt to make use of the natural environment by their experience of where rich fishing grounds are to be found, by utilizing the fertile alluvial deposits for agriculture and animal husbandry and suchlike.

Any interventions in the river system should be seen against this background, interventions that may arise out of water-use planning at the national level (cf. Para. 4.1). However wide the scope of such planning, and however much attention is devoted to the poorer sections of the population and the environment, only at the regional level can a proper balance be struck between national ambitions and local needs and interests. Here, top-down and bottom-up planning will meet one another and require integration. To date, there have been too many examples of rigid top-down planning making it impossible for local requirements to be respected. That this is above all due to one-sided preoccupation with the desires of the urban population and industry is illustrated by the observation made by Awachie (1981) that not a single dam in Africa, constructed or scheduled, is linked with a rural electrification programme (with the exception of the Koussou Dam in Ivory Coast).

Much planning centres on the interests of the national economy, in itself of course legitimate. Often enough, though, scheduled projects do not even get anywhere near meeting the national-economy objectives, neither do they function as planned. In many cases the ultimate cause is an absolutely inadequate knowledge, on the part of the planners, of the social and ecological situation existing on a regional scale. As a result, there is often a complete lack of (essential) motivation on the part of the local population. As a solution, local participation in the planning procedure is subsequently suggested, a concept that is not always well-defined. In our opinion, planners should make a clear distinction between the various interested parties concerned, each with their own specific man-environment interaction. This interaction should be clearly defined, for in this way the planning operation can be rendered more transparent. Planners should make a well-argumented and sound choice as to which of the interested parties is to be given priority in the planning procedure. That this was often not the case in the past is well illustrated by the fact that women in the Third World were for years excluded from planning entirely, even though they represent the greatest development potential: in many regions, women have for centuries fulfilled the most important role in traditional agriculture and in traditional environmental management.

Any aggravation of conflicts already existing at a local level should be avoided, however. The creation of organizations and the establishing of communal-training and political-education projects are in part directed towards cultivating collective attitudes and feelings of responsibility and resilience in the planning exercise. In addition, any groups whose interests are damaged should be compensated or awarded damages. It is also extremely important that an 'organic' approach be taken during a development programme. Projects that start out on a small scale and gradually grow in size and scope allow for participation and obviate serious misunderstandings between the local population, government and project bureacracy (cf. Marchand & De Groot, 1985).

As an aid to improved incorporation of the ecological and social dimension in regional planning, a number of guidelines and principles are provided in Para. 4.5.

## 4.4 Project planning

The third step in the river basin planning process is project planning. Let us assume that both the previous phases have been carefully followed through, with ample attention being given to nature and the environment. Even then, planning at this third level requires that a thorough study be made of the basic situation with respect to the physical environment, with forecasts being made of anticipated environmental changes. It is perfectly possible for a project designed to improve the functioning of a river (e.g. reforestation, as an erosion-combatting measure) to result in ecological problems at the implementation level (e.g. introduction of exotic tree species in monocultures). What is important at this level, therefore, is to draw up alternatives within the context of actual implementation, i.e. alternative locations and design variants that are both financially viable and socially and economically compatible. In the Appendix, examples are provided for the various classes of intervention. For each of these, an indication is given of the environmental effects that may follow.

Two types of environmental effects are easily forgotten, viz. the secondary and cumulative effects. Once completed, the project will by its simple presence enable new activities and interventions to be undertaken. The secondary activities following in the wake of a completed scheme may in turn exert an influence on the environment: the secondary effects. The construction of a dam for irrigation and hydropower generation, for instance, may have a strong power of attraction for (agro-)industry. After all, there is an energy surplus and raw materials for production and food for employees are catered for by local agricultural output. What we in fact see is a complex of relationships between the initial, planned activity - which is often intended to stimulate development - and the potential 'magnet' effect such a project can create.

Ideally, these secondary effects should be incorporated in the regional planning. If this is not the case, and there is a real likelihood of such effects occurring after an intervention, it becomes essential to go back to the previous planning phase. This applies equally to the cumulative effects, which only become apparent when a survey is made of the overall environmental load or damage in the region concerned. If the net effect of yet another small-scale impoldering operation is to destroy the last valuable stretch of riparian forest, where the last colony of colobus monkeys has its home, then this is in fact due to insufficient attention being paid to cumulative effects in the past. The key thing here is to determine the safe thresholds that are not to be transgressed, e.g. what is the minimum ecosystem size required by a particular threatened species if it is to survice in the longer term. In this context, cumulative effects that reinforce one another (the so-called synergistic effects) are also important. With these, the total impact is greater than that expected from simply adding up the individual effects. A reduction in the overall size of a given species' habitat, combined with isolation through e.g. fragmentation of the habitat, implies a far higher risk of extinction than would be expected merely from considerations of biotic area reduction. Another good example of such synergistic effects is the fact that discharges of several individual pollutants may interact to create new chemical compounds that are far more toxic than the original substances.

## 4.5 Guidelines for river-basin management

1) **Preservation or improvement of the spontaneous functions fulfilled by the river, by:**
   - restoring erosion/sedimentation processes, through countering increased silt loads caused by upstream erosion (improvement of watershed management!);
   - preserving genetic diversity, through conserving natural areas and threatened species;
   - preserving the selfpurifying capacity of the river, through combatting pollution (water-treatment plants, at-source anti-pollution measures).

2) **Conservation of the natural values of the river basin, by:**
   - preventing deterioration/destruction of natural resources, by means of legislation (incl. compulsory environmental impact assessments) directed towards industrial development, impoldering schemes and drainage activities;
   - establishing reserves in the most vulnerable ecosystems, with surrounding buffer areas;
   - establishing environmental education programmes;
   - initiating programmes to promote sound, durable exploitation of ecosystems (particularly fisheries, herding and forestry).

3) **Conservation of the river basin's extensive exploitation functions, by:**
   - guaranteeing the protection of productive zones, such as flood plains, estuaries and lakes, by allocating appropriate quantities of water (in relation to 4) and by means of the programmes mentioned sub 2);
   - implementing reafforestation schemes for supply of firewood, in relation to sound watershed management (cf. 1).

4) **Development of sustainable intensive exploitation functions, by:**
   - drawing up a water allocation plan for the entire river basin, to achieve a better match between water demand and supply; this should give due consideration to the water requirements of the spontaneous functions (1), natural values (2) and extensive exploitation functions (3);
   - developing small-scale projects e.g. irrigation, fishponds, forestry;
   - improving product processing, sales and marketing, e.g. by making better use of the river as a transport route;

- ensuring that detailed plans for the above objectives are thoroughly checked against the other criteria (1-3 and 5) within the framework of an environmental impact assessment procedure.

5) **Improvement of the overall health situation in the river basin, by:**
   - combatting waterborne diseases;
   - improving the food situation, both quantitatively and qualitatively;
   - establishing a drinking-water programme for rural areas, with the objective of making clean, healthy water available for the whole population;
   - ensuring that detailed plans for the above objectives are thoroughly checked against the other criteria (1-4) within the framework of an environmental impact assessment procedure.

6) **Guiding principles for regional planning** (from: De Groot & Van Tilburg, 1985):
   - work with, not against the environment;
   - start work from the existing situation, i.e. existing infrastructure, technical know-how, perceptions of subsistence security, cultural needs etc.;
   - protect the authentic evolution of local culture, institutions and know-how;
   - when undertaking action or introducing social change, prefer those actions involving decision-making at the lowest possible level;
   - assess the carrying capacity of extensive agricultural and water-use systems, as well as their present value;
   - assess the required inputs for intensive systems of land and water use and their value if a growing number of people are to be fed;
   - intensify or introduce intensive land- and water-use systems at locations with the best soil and superior climatological and market conditions;
   - preserve, develop and utilize nature's spontaneous functions;
   - when planning reserves for species or ecosystems, endeavour to make them as large, as varied and as interconnected as possible;
   - preserve rare species and ecosystems in their authentic ecological setting, giving due consideration to the long-term effects of isolation;
   - avoid land- and water-use systems exhibiting irreversible dependence on a single crop or market (especially narrow or foreign markets), also on the input side.

## 4.6 An example: the Niger Basin

With a length of 4200 km, the Niger is West Africa's major river. This river basin, encompassing an area of approximately 2 million square kilometres, spreads over no less than nine countries, five of which belong to the Sahel region. The water regime is characterized by pronounced peak discharges following the rainy season and low discharges in the dry season. Because of its size and the fact that a major part of the river's course is through semi-arid and arid land, the Niger constitutes one the Sahel region's main sources of water. At the same time it represents an impressive potential source of hydroelectric power. Only a small section of the river is permanently navigable, viz. in the Nigerian bottomlands.

These factors have resulted in creation of a number of hydraulic engineering works and irrigation projects along the river, and there are plans for a very large number of similar new schemes. At the time of writing, 19 new dams are projected (see Fig. 4.1), while many thousands of hectares of agricultural lands have been earmarked for irrigation, using water from the Niger. Recognition of the enormous consequences for the water regime and for water distribution among the various countries concerned has moved the Niger Basin Authority, a transnational body set up by the nine riparian nations (Guinea, Burkina Fasso, Mali, Niger, Nigeria, Chad, Cameroon, Benin and Ivory Coast) to commission a study, the aim of which is to establish a mathematical model of the river's hydrology. This model, major components of which have already been completed, can be used to investigate the effects of any new projects on the water regime of the river basin (Niger Basin Authority, 1982).

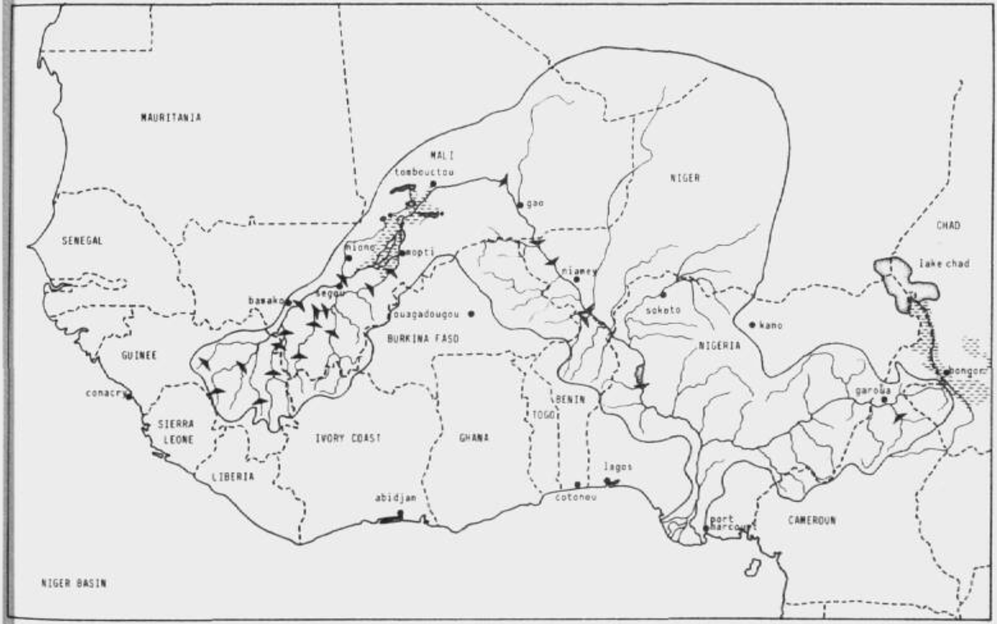



Figure 4.1 Niger river basin, showing scheduled and existing hydraulic engineering projects (From: Niger Basin Authority, 1982)

Mali, the country with the greatest area of Niger basin within its borders (589,000 $km^2$), may serve as an instructive example of the many interests that must be considered when establishing an overall watershed management scheme.

Downstream of the capital Bamako the river broadens to form an inner delta, which is flooded each year creating an inundated area of some 30,000 $km^2$ . This flood plain represents one of the major wintering areas for West European birds and, furthermore, produces 100,000 tonnes of fish annually, provides fertile grazing lands for about 1 million head of cattle and contributes significantly to the country's output of rice and other crops. On the other side of the balance sheet, these floods, occurring as they do in one of the most arid parts of Mali (annual precipitation: approx. 400 mm/. cause just about half the country's annual influx of water to evaporate.

At the moment three large dams have already been constructed upstream of the delta, designed for hydropower generation and irrigation. By means of a distributing dam at Markala, part of the water is diverted from the main stem through the Canal du Sahel to a large-scale irrigation scheme for approx. 50,000 ha, which is managed by the Office du Niger. The rest of the water is retained by a dam at Selingue in a 2 billion cubic metre reservoir and discharge regulated to serve power-generating turbines and (in the future) irrigation schemes in the reservoir's vicinity.

The irrigation scheme managed by the Office du Niger provides a good example with which to give an indication of the differences in yield per unit water supply between irrigated agriculture and the traditional production systems of the floodplain. Table 4.2 shows the actual production characteristics of the two systems side by side.

| | NIGER INNER DELTA | | | | | OFFICE DU NIGER | |
|---|---|---|---|---|---|---|---|
| | meat | milk | fish | rice | TOTAL | rice | TOTAL |
| Total weight | 10,372 t | 119,454 t | 100,000 t | 79,400 t | | 100,000 t | |
| Weight/100 $m^2$ | 44 g | 506 g | 427 g | 235 g | | 5,003 g | |
| Value/100 $m^2$ | 18 FM | 202 FM | 171 FM | 26 FM | 417 FM | 550 FM | 550 FM |
| Protein yield/100 $m^2$ | 8 g | 17 g | 77 g | 18 g | 119 g | 190 g | |
| Energy yield/100 $m^2$ | 83 kcal | 318 kcal | 401 kcal | 853 kcal | 1,656kcal | 13,749kcal | |
| Inputs/100 $m^2$: | | | | | | | |
| fertilizer | 0 | 0 | 0 | 0 | | 11 FM | |
| management, services etc. | 0 | 0 | -very small- | | | 84 FM | 120 FM |
| oxes, ploughs, etc. | 0 | 0 | -very small- | | | 25 FM | |
| Margin of profit/100 $m^2$ | | | | | 417 FM | | 430 FM |
| Loss of interest/100 $m^2$ | | | | | 0 | | 1,084 FM |
| Net margin of profit/100 $m^2$ | | | | | 417 FM | | -654 FM |

Assumptions: - 1 kg fish = 400 FM = 1 kg meat = 1 kg milk
- 1 kg rice (paddy) = 110 FM
- 1 kg fertilizer = 235 FM
- construction costs of 1 irrigated ha. = $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 oxes, ploughs etc. of farmer = 13,200 FM/ha

Note : - 1 FM = $0.001
- the sugar production is not included in this comparison (both in terms of water use and in yields)

Table 4.2 Yields per unit water for the Delta and the Office du Niger (From: Drijver & Marchand, 1985)

It can be seen that paddy rice cultivation yields 10 times as many calories and almost twice as much protein as the floodplain (per unit volume of water). On the other hand, if we consider the composition of the food produced, the floodplain clearly yields a far wider variety of foodstuffs, viz. high-protein sources such as meat, milk and fish in addition to rice.

On the input side, we see that the floodplain system requires scarcely any inputs other than labour. The higher production level of the irrigated land is due above all to the inputs of fertilizer, labour and management. Net yields in financial terms are thus approximately equal. If, finally, we take into account the cost of developing the irrigation scheme, the financial balance sheet at once becomes markedly negative. What we see here is the 'shadow price' of the work done by nature in the floodplain for man: annual supplies of water in the form of inundation plus natural fertilizater in the form of alluvial deposits (spontaneous functions!). In the case of the irrigation system, this configuration must be created artificially using man-made fertilizers, digging a system of canals and constructing a distributing dam in the river. Besides the creation of physical structures, a complete new social infrastructure also had to be built up. In view of the fact that in Mali there scarcely existed a tradition of irrigation system management, development of such a system was accompanied by a multitude of social problems. These are still manifest in organizational difficulties, uncertainty and a lack of motivation on the part of the farming community, consequently leading to agricultural yields that are below expectations.

A number of 'marginal notes' should be added to this comparison. The potential yield of the paddy rice area, for instance, could be far higher than the current average of 2 t/ha. In Asia, yields of 10 t/ha are no exception. It should be remembered, though, that Asia has a long-standing tradition of irrigation, the system having evolved step by step at relatively low cost and involving a comparatively minor influx of foreign know-how. With the current problems in the field of management and social organization, though, actual yields in Africa will - for the time being at any rate - remain too low to render the irrigation scheme financially sound.

For a country's overall welfare, however, the financial profitability of a project is by no means the only important aspect. If it is possible to reduce foreign-exchange-consuming food imports by means of an irrigation scheme whose deficit budget is balanced by soft loans or gifts, the undertaking may indeed become economically attractive.

A second aspect excluded from the comparison concerns differences in harvest security between the two systems. The present drought in the Sahel region has not left the floodplain unaffected. Output from cattle herding and fisheries has reached a tragic low. During periods like this, irrigated culture often forms the only source of food production. It is therefore understandable that there is a desire to substantially extend the area under irrigation. Plans for the coming years assume 17 dams upstream, with a total of 160,000 ha of irrigated land. Even in years that are hydrologically normal or wet, however, this implies an extremely significant reduction of the Delta area, with a proportionate reduction in fish, meat and floodplain-culture production.

This leads to the conclusion that, for a country such as Mali, the solution is to be sought in (small-scale) irrigation combined with development of existing floodplain production systems. With respect to the latter, there is room for improvement in terms of increased yields, e.g. through improved water management using intermediate polders ('submersion controlee'), improved product processing, e.g. conserving of fish, and introduction of new exploitation methods such as game utilization, new crops etc. Mitigating and compensating measures to prevent the scheduled hydraulic engineering projects having a negative impact on the Delta's productivity would appear to constitute financially and economically sound policy, both for the local population and for the national economy.

As long as compatability with other, existing systems of land use and durability are guaranteed, these developments can strengthen the role of the floodplain as a source of protein within the framework of regional development.

## 5 INTERVENTIONS

### 5.1 Intervention characteristics

All the river-basin interventions discussed in the present report have in common that they significantly influence the hydrological regime in one way or another. Table 5.1 lists a number of common types of human intervention. This list is based on the official project list issued by the Directorate-General for International Cooperation of the Dutch Government, i.e. they are activities that can be influenced through Dutch development cooperation channels. This also means implies that autonomous developments and activities are not included in the list below.

An intervention is an act of outside interference in a system, preceded by a human decision that is the outcome of an interplay of social forces. Interventional activity forms part of a planning process governed by politics, independent of the level considered. A study of the consequences of interventions cannot ignore the nature and origins of this planning process.

| | INTERVENTIONS | EXAMPLE |
|---|---|---|
| 1* | Earthen dams in (coastal) creeks | Guinea-Bissau |
| 2* | Earthen dams in minor tributaries | Sri Lanka tanks |
| 3* | Dam in main river stem | Kafue/Kainji/Mahaweli/Nile |
| 4* | Storm-surge/saltwater dam | Diama dam (Senegal) |
| 5* | Upstream marsh drainage | Kisii (Kenya) |
| 6* | Impoldering (drainage) | Logone/Tana Delta/Rawa Sragi |
| 7* | Arid-land irrigation | Office du Niger/Mahaweli |
| 8* | River canalization/normalization | Jonglei Canal |
| 9 | River dredging | Ganges |
| 10 | Drinking-water reservoir | Lac du Guier (Senegal) |
| 11 | Sewer system + wastewater treatment | |
| 12 | Harbour development | |
| 13 | Urban flood protection | Bangkok/Djakarta |
| 14 | Industrial development | |
| 15 | Erosion control | Kalikonto (Indonesia) |
| 16 | Fisheries development | Lake Victoria (Tanzania) |
| 17* | Aquaculture (fish-ponds) | Indonesia |
| 18 | Aquatic weeds control | Egypt |
| 19 | Waterborne disease control | onchocerciasis |
| 20 | Mining | Zaire |

Table 5.1 Frequently encountered river-system interventions (Interventions marked with a * are discussed in more detail in the Appendix.)

In addition to the variety of effects resulting from the diversity of specific interventions (discussed in the Appendix), there are also a number of general characteristics common to many interventions. Below, we discuss two of these.

Interventions may take place on a large or a small scale. Usually the scale is indicated by the size of the project in hectares, but in some cases capital-intensiveness may serve as a criterion.

Closely linked with the scale of an intervention is the level of government involvement. Large-scale, capital-intensive projects will almost always form an object of government attention. A case in point is the Mahaweli Ganga Project in Sri Lanka, discussed at the end of this chapter.

## 5.2 Impact of interventions

Each and every intervention affects the environment, both in a positive and in a negative sense. In an environmental impact assessment statement, these effects - often existing as a chain of effects - can be forecast in a quantitative fashion, making explicit their mutual relations. At the same time, an attempt should be made to indicate the resultant impact on the various object variables defined. In the present report, the effects are considered separately from one another, and are treated in a qualitative manner.

We can distinguish five types of effect chains:
- impact on the location (5.2.1),
- changes in water quantity (5.2.2),
- changes in water quality (5.2.3),
- changes in the availability of natural resources (5.2.4), and
- secondary effects (5.2.5).

As regards the object variables, we have opted for a subdivision according to the functions and values of the river basin (see Chapter 3), supplemented by the variable 'health', which is closely related to environmental quality (see Para. 3.5) and is also often included in planning procedures as a separate sector.

### 5.2.1 Impact on the location

This heading covers the impact on physical structures resulting from the land requirements of the intervention, e.g. loss of habitat and valuable ecosystems, changes in land use etc. The scale of these effects is governed strongly by the size, lay-out and routing of the intervention.

### 5.2.2 Changes in water distribution (quantity and timing)

Many river-basin interventions have the express objective of modifying the water regime in such a way as to enable more intensive use to be made of water resources. Under this heading of effects we aim to make explicit the unintentional side-effects of a modified water regime. In this, particular attention should be given to traditional land-use patterns and the natural ecosystems upstream of the site of intervention (dam, irrigation scheme, canal etc.), which will have become adjusted to the water regime existing prior to the intervention.

For large-scale water-management interventions, specifically, an impact on the entire river basin is to be anticipated. Man's increased potential for regulating streamflows by means of hydraulic engineering works makes it essential to establish a watershed management plan. The institutional capacities and deliberation processes involved in such an exercise are discussed in Chapter 4 'River-basin management'.

### 5.2.3 Changes in water quality

Interventions aimed at intensification are virtually always accompanied by a greater influx of environmental pollutants (e.g. irrigation project employing fertilizers and pesticides). Experience has shown that a low priority is given to adequate management of such contaminants, which constitute a severe threat to vulnerable ecosystems.

More intensive water use, together with an increase in cultivated land area means that the water encroaches upon more places, resulting in a greater number of stagnant pools. In these pools various disease-carrying organisms can develop (bilharzia, malaria). Aquatic weeds can thrive in open bodies of water, which in turn may result in oxygen deficiency of the water.

For soil fertility, traditional floodplain culture systems are often dependent on the alluvial silt deposited during periodical inundation. Upstream interventions (e.g. dams) may disturb this process of silt supply, necessitating fertilizer inputs, leading to a number of secondary problems.

Fishery activities may be seriously threatened by water pollution and depressed oxygen levels caused by agriculture and dams upstream.

### 5.2.4 Changes in natural-resource availability

For their livelihood, men and women farmers are dependent on a variety of natural resources: water, land and such living resources as home gardens, forests for firewood and timber, herds and fish. Labour, too, may be considered as a natural resource. A healthy environment can supply all these resources, as long as its vital carrying capacity is not exceeded. Traditional societies usually consist of extended families, interwoven on the basis of a kind of 'labour economy'. The quantity of natural resources a family has at its disposal is frequently governed by the amount of labour it can provide. The fact that labour represents an exchangeable commodity between families prevents any substantial socio-economic differences arising. On the one hand, this equilibrium between man and his environment is disturbed by overpopulation, which may lead to the carrying capacity of the environment being exceeded. In such cases, intervention may be necessary. On the other hand, the balance may be upset by the introduction of a money economy, usually accompanied by the introduction of both large- and small-scale projects. In contrast to labour, money can be accumulated, rapidly leading to a high degree of social differentiation.

Through a process of capital-intensive intervention, men and women farmers are often compelled to embark upon commercial production. The natural resources (i.e. the environment) are commercialized. Within the terms of the newly created production system, farmers become one another's competitors and social decision-making levels lose their importance, which also results in an impoverishment of control over collective resources. In short, this implies neglect of the environment.

### 5.2.5 Secondary effects

In the wake of outside intervention, newly scheduled developments may follow, bringing with them their own, added impact on the environment. A familiar example is the industrialization of a region following construction of a hydroelectric dam. Another form of impact is represented by fish culture in newly constructed irrigation ponds.

Generally speaking, it may be said that in association with an intervention, the infrastructure of a river basin undergoes improvement, opening up the region for new activities with their own specific repercussions for the environment.

## 5.3 An example: the Mahaweli Ganga project, Sri Lanka

The River Mahaweli Ganga has its source in the mountains around Kandy, Sri Lanka's so-called 'wet zone', and cuts through a large part of the 'dry zone'. The difference between the two zones lies in the fact that the wet zone has two pronounced monsoon seasons, the dry zone only one.

The Mahaweli Ganga Project impinges not only on the Mahaweli Ganga river basin, but also on that of the Amban Ganga and the Maduro Oya, two of its major tributaries. Furthermore, the scheme is to be linked up with the Kalo Oya basin in the mid-west of Sri Lanka by means of a 'trans-basin' canal.

According to the official objectives stated by the national government, the project serves three purposes:

1. electrical power generation, for accelerated industrialization (cf. Para. 5.2.5, 'Secondary effects');
2. development of irrigated agriculture, obviating the need for (expensive) rice imports;
3. reduction of population pressure and unemployment in the wet zone by means of a resettlement programme (Sogreah, 1972).

The river basins of the Mahaweli Ganga and the Maduro Oya, in particular, harbour rich ecosystems. The river banks support riparian forest containing a large number of rare tree species. In addition, the estuaries of the Mahaweli are a major habitat for many species of fish and shrimps. The most important ecosystems of the two rivers, however, are the floodplains, inundated several times a year as dictated by the river regime. These areas are the spawning grounds of fish and other aquatic and semi-aquatic species. Large game is to be found here, and the economic value is also significant: livestock farming and small-scale rice and vegetable culture constitute a sustainable livelihood for many of the region's inhabitants.

The project involves the construction of a number of dams, designed both for hydropower generation and for land irrigation (See Fig. 5.1). For this purpose, infrastructural development is already underway in a considerable area of the aforementioned river basins.

An unofficial, yet generally explicit objective of the scheme is the political survival of the UNP, the governing party of the day. They have made their political position ultimately dependent on the scheme's success.

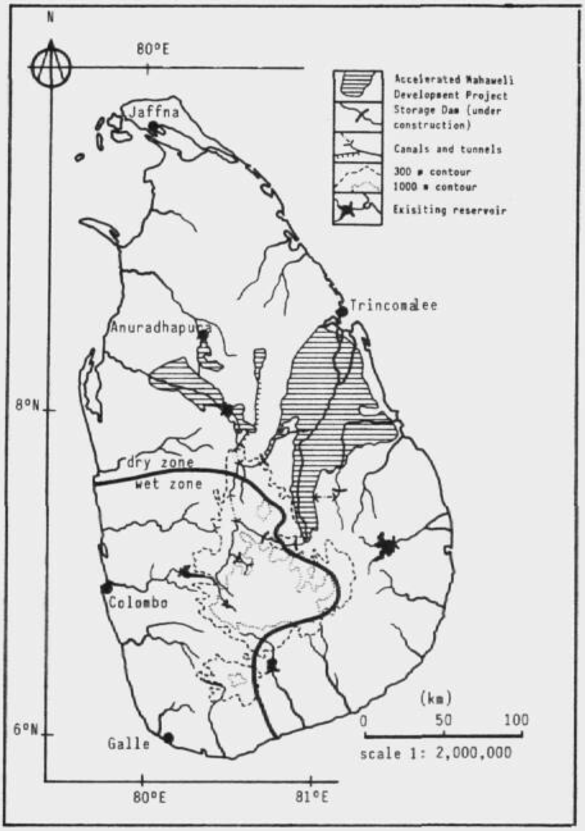



Figure 5.1 Overall plan of the Mahaweli Ganga project

Various studies (TAMS, 1981; Drijver, Toornstra & Siriwardena, 1985) have indicated the enormous environmental impact of this scheme. The construction of reservoirs at the river's source has resulted in the loss of extensive areas of valuable agricultural land and ecosystems. Not all those originally living in this region have been resettled in the irrigation project. Those remaining behind have been compelled to take recourse to areas further up the hillsides, on marginal lands. In addition to illegal tree-felling by contractors, this constitutes a major cause of deforestation and erosion in the reservoir areas (cf. Para. 5.2.1, 'Impact on the location').

Elsewhere in the wet zone there is plenty of lucrative plantation culture: tea, tobacco and rubber. The tobacco plantations, in particular, as well as the poorly managed rubber and tea operations are causing serious erosion. Even now, these plantations are still being extended (mainly tobacco) at the cost of traditional food farming. In Sri Lanka's hierarchically organized and politicized society, land-use priorities cannot constitute anything but political decisions, based on the immediate interests of the politicians of the day (cf. Para. 5.2.4, 'Natural-resource availability').

The floodplains further downstream are also threatened by the scheme. Because discharge levels will be subject to artificial regulation (levelling off of peak flows), the extent of the floodplains will be reduced (cf. Para 5.2.2, 'Changes in water distribution'). This shrinkage in area is not the only threat, though. Increased human pressure on the adjacent, newly irrigated areas and the discharge of polluted drainage water (pesticides, fertilizers) into the vulnerable floodplain ecosystems form major threats to the area (cf. Para. 5.2.3, 'Changes in water quality'). The fact that these effects have not been studied in any detail, not to mention the lack of any mitigating countermeasures, is in part due to the (still) minimal interest in environmental problems existing in Sri Lanka.

As mentioned above, under the resettlement scheme people are being moved into the irrigated areas. As population pressure there increases, the amount of wild game decreases. At the same time, the process of socio-economic differentiation described in general terms in Para. 5.2.4 is already underway. This in turn makes it more and more difficult for a large group of people to undertake sound management of their surrounding environment.

Special mention should be made of the fact that women, who traditionally earned an income in 'dry' agriculture, are now excluded from the production process. As a result, and reinforced by the above-mentioned process, poverty is widespread in the newly-developed areas. Due to a combination of mismanagement, inadequate construction and the disappearance of an extended-family structure, rural life has now become a question of the 'survival of the fittest' (Drijver, Toornstra & Siriwardena, 1985). Illegal tree-felling and land encroachment ('squatting') are taking place on a large scale, and waterborne diseases are rife. Environmental degradation, already a traditional ill (especially soil degradation), has been reinforced by this project.

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## APPENDIX: IMPACT MATRICES OF INTERVENTIONS AND RECOMMENDED MEASURES

This appendix is especially made for those who are engaged with a specific intervention in a river basin. It gives quick reference of the expected impacts and shows on which target variables these impacts have their influence (e.g. on the health of people or on the functions of the river basin). This is denoted with an 'X' in the column of the influenced target variable.

Each 'X' is accompanied with one or more numbers refering to possible alternatives c.q. mitigating or compensating measures. Every list of recommended measures begins with 'Recommendation 0': this recommendation stresses the importance of a pre-project inventory and an evaluation of possible alternatives. Depending on the kind of intervention and on the characteristics of the project area some aspects will get more attention during the inventory phase than others. The alternatives too, will differ significantly for one intervention or the other.

As stressed above, each plan for an intervention must be preceded by an inventory of the pre-project situation. In this inventory, the following elements always need to be assessed:

- physical environmental conditions (soil- and vegetation mapping, hydrology, climat);
- valuable nature areas, threatened flora and fauna;
- spontaneous functions of the river basin and existing land use systems;
- social structures and political context.

| INTERVENTION: Earthen dam in coastal creeks<br>EFFECT - CHAINS | natural values | sponta- neous functions | intensive exploi- tation | exten- sive ex- ploitation | health |
|---|---|---|---|---|---|
| | | | target variables | | |
| a) location - risk of development of acid sulphate soils ('cat clays') | - | - | $x^2$ | $x^2$ | - |
| - destruction of mangroveforests --▶ negative impact on shrimp fishery | $x^1$ | $x^1$ | - | $x^1$ | - |
| - destruction of traditional fish methods in creeks | - | - | - | $x^{0,1}$ | - |
| - maintenance problems --▶ erosion | - | - | $x^4$ | - | - |
| b) water quantity | | | | | |
| - more water available for wet rice culture --▶ concentration of people and cattle | - | - | - | $x^3$ | - |
| c) water quality | | | | | |
| - stagnant water behind the dam give rise to waterrelated diseases and development of aquatic weeds | - | - | $x^4$ | $x^4$ | $x^2$ |
| d) disposition of natural resources | | | | | |
| - earnings from fishery by women become impossible --▶ malnourishment and social conflicts | - | - | - | $x^{0,1}$ | $x^{0,1}$ |
| - intensification and monoculture of agriculture destroys trad. agriculture --▶ socio-econ. differentiation and conflicts | - | - | $x^{0,1}$ | $x^{0,1}$ | - |
| e) secondary impacts | | | | | |

Alternatives & mitigating measures for
earthern dams in coastal creeks.

0. Inventory of the pre-project situation: take notice of the ways by which the local people prevented or mitigated the development of Acid-sulphate soils. Are there any other specific traditional water-management aspects of present polders?
   Alternative: improvement of existing dykes.

1. Cost-benefit analysis must include social costs (e.g. loss of womens income from fishery).

2. Development of a watermanagement plan to prevent waterborne diseases and cat clays. E.g. cat clay development can be counteracted by periodical flushing with seawater in dry season (brachish water has the capacity to wash out the acid 10 times faster than fresh water does). The salt can then be washed out with rain water. (Pons, 1984; Oosterbaan, 1982.)

3. A sound land-use planning to prevent an overexploitation by man and cattle.

4. Development of a maintenance programme for dams and polders.

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L.J. Pons: Kort rapport van een bezoek aan het Nederl. DGIS-Cultuurtechnisch Projekt no. 2: Projecto Engeharia Rural, Regio Quinara, in Guinee-Bissau. Wageningen, 1984

R.J. Oosterbaan: Natural and social constraints to polder development in Guin-Bissau. Paper of the Int. Symp. Polders of the World, ILRI, 1982

INTERVENTION: Earthen dam in minor tributaries

| EFFECT - CHAINS | natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| | target variables | | | | |
| a) location - more water available --▸ more agricultural possibilities --▸ concentration of cattle (esp. in arid regions) and people --▸ deforestation and overgrazing | $x^{1}$ | - | - | $x^{0,1,6}$ | - |
| b) water quantity | | | | | |
| - possibilities for irrigation | - | - | $x^{2}$ | - | - |
| - many dams may have a cumulative impact --▸ decreased peak discharges and less water availability downstreams | $x^{2}$ | $x^{2}$ | - | $x^{2}$ | - |
| c) water quality | | | | | |
| - development of waterborne diseases and aqatic weeds in the stagnant water behind the dam | - | - | - | - | $x^{3,4}$ |
| - drainagewater can be contaminated with pesticides and fertilizer --▸ water quality downstreams deteriorates | $x^{4}$ | $x^{4}$ | - | $x^{4,5}$ | $x^{4,5}$ |
| d) disposition of natural resources | | | | | |
| - dry farming becomes less important --▸ marginalisation esp. of women | - | - | - | $x^{1,3}$ | $x^{1,3}$ |
| - commercialisation of natural resources; deforestation | - | - | - | $x^{1,6}$ | - |
| e) secondary impacts | | | | | |
| - development of aquaculture | | see ' aquaculture development' | | | |
| - sedentarisation of nomads --▸ social conflicts | - | - | - | $x^{6}$ | - |

Alternatives & mitigating measures for
earthern dams in minor tributaries.

0. Inventory of the pre-project situation: take special notice of traditional land use systems: importance of wet and dry farming. Take also special notice of the original water management system(s).
   Alternative: development of dry farming.

1. A sound land use planning to prevent deforestation and overgrazing of the land and to assure a diversified land use. Use of the natural resources has to be kept within the boundaries of the carrying capacity. This can conflict with the wish to fulfil everymans basic needs.
   A solution can only be reached if social structures are not upset and if extra imputs for the agricultural and foresty sectors are provided.

2. Development of a watermanagement plan based on traditional customs in order to effectively and justly distribute the water, to ensure adequate drainage and to prevent waterrelated diseases.

3. Agricultural extension which is also directed towards and executed by women.

4. Instruction on how to use pesticides and fertilizer.

5. Creation of drinkingwater wells.

6. Intensive supervision and creditprogramme together with the development of alternative sources of income in order to facilitate the compulsory sedentarisation of cattle nomads.

INTERVENTION: Storm surge / saltwater dam in estuary

| EFFECT - CHAINS | target variables: natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| a) <u>location</u> - barrier for fish, shrimps, manatees etc. | $x^{0}$ | $x^{0}$ | – | $x^{0,1}$ | – |
| b) <u>water quantity</u> | | | | | |
| - change of streampatterns along the coast can lead to ersion | – | $x^{3}$ | – | – | – |
| - tidal influence behind the dam is lost --→ intertidal flats become permanently exposed or inundated --→ foraging grounds for waders and other waterfowl are lost | $x^{0}$ | $x^{0}$ | – | – | – |
| c) <u>water quality</u> | | | | | |
| - typical estuary environment (salt - fresh water gradient) lost --→ mangroves upstream disappear. High primary production will decrease in the new fresh environment | $x^{0,2}$ | $x^{0,2}$ | – | $x^{0,2}$ | – |
| - reservoir increases pressure on groundwater --→ salination/soils | – | – | $x^{4}$ | $x^{4}$ | – |
| - exchange of silt and org. matter decreases --→ fishery affected | – | – | – | $x^{2}$ | – |
| d) <u>disposition of natural resources</u> | | | | | |
| e) <u>secondary impacts</u> | | | | | |
| - upstream more possibilities for irrigation | | see ' arid land irrigation' | | | |

Alternatives and mitigating measures for
storm surges/saltwater barriers in estuaria

0. Inventory of the pre-project situation. Take notice of the nursery-function of estuaries for shrimp, several fish species, wildlife (manatees, turtles, crocodiles, Hippos, birds) and rare wetland eco-types such as mangroves and seagrasses.
   Alternatives: * Semi-open dams
   * Raise of embankment
   * Flowregulation upstream

1. Fishladders and sluices for migrating fish and shrimp species.

2. Barriers should be situated, as possible, upstream of mangroves and estuaries.

3. One should take into account the extra costs for coastal protection, after construction of the dam.

4. The maximum waterlevel in the created reservoir should be kept low to preserve as much as possible of the original environment.

| INTERVENTION: Storage dam in main river system | target variables | | | | |
|---|---|---|---|---|---|
| EFFECT - CHAINS | natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
| a) <u>location</u> reservoir creation implies: | | | | | |
| - loss of agriculture-, fish- and herding grounds | $X^{0,1}$ | $X^{0,1}$ | $X^{0,1,2,3}$ | $X^{0,1,2,3}$ | - |
| - loss of valuable ecosystems | $X^{0,1}$ | $X^{0,1}$ | - | - | - |
| - blocking of migration routes of fish, cattle and wildlife | $X^{5}$ | - | - | $X^{5}$ | - |
| - resettlement problems --➔ see 'arid land irrigation' | | | | | |
| b) <u>water quantity</u> | | | | | |
| - regulation of river discharges: decreased peak discharges, delay in flooding and increased low water discharges | $X^{6}$ | $X^{6}$ | $X^{6}$ | $X^{6}$ | - |
| - new settlements on slopes of reservoir lead to deforestation --➔ erosion and increased water folw in rainy season | - | - | $X^{4}$ | - | - |
| c) <u>water quality</u> | | | | | |
| - decreased peak discharges --➔ salt intrusion in delta | $X^{6}$ | $X^{6}$ | - | $X^{6}$ | - |
| - aquatic weeds development in reservoir | - | - | $X^{9}$ | $X^{9}$ | $X^{9}$ |
| - reservoir acts as silt trap --➔ loss of fertility of soils | - | $X^{4,8}$ | $X^{4,8}$ | $X^{4,8}$ | - |
| - reservoir stratification --➔ downstreams $O_2$ shortage and toxic matter | $X^{7}$ | $X^{7}$ | - | $X^{7}$ | $X^{7}$ |
| d) <u>disposition of natural resources</u> | | | | | |
| - resettlement leads to use of marginal lands --➔ erosion | $X^{1,3,4}$ | $X^{1,3,4}$ | $X^{1,3,4}$ | $X^{1,3,4}$ | $X^{1,3,4}$ |
| - competition between export oriented agriculture and subsistence agriculture for scarce grounds | - | - | $X^{2,3}$ | $X^{2,3}$ | $X^{2,3}$ |
| e) <u>secondary impacts</u> | | | | | |
| - development of reservoir fishery | - | - | $X^{7}$ | - | - |
| - electricity generation leads to industrialization | | | | | |

Alternatives and mitigating measures for
a storage dam in the main river channel.

0. Inventory of the pre-project situation. Take notice of the migration patterns of cattle and wildlife.

1. Cost-benefit analysis which also takes into account the costs, caused by the loss of original agricultural lands and important ecosystems. The enormous social costs of resettlement projects must be given due consideration.

2. The resettlement planning program should be available before the start of the project. Settlers should have the possibility to participate in the planning program. The planning program must give guarantees that sufficient resources are available in the new created environment. Men and women should have equal access to these resources.

3. Farmers, who stay behind near reservoir, must be held back from clearing marginal and erosion-susceptible lands. Small agro-industry and adequate homegardens could provide an income.

4. The remaining farmers could also play an important role in the watershed-management program, eg. reafforestation-activities.
Within such a watershed-management program, soil conservation measures like reafforestation, contourploughing, mulching etc are very important.

5. The choice for the location of the reservoir should also take into account the migration patterns of cattle and wildlife. Fishladders could service the fish-routes.

6. A management program for a storage dam should not only take into account irrigation and electricity needs but also nature values, spontaneous functions and exploitation values of floodplains and estuaries downstream.
The preservation of these latter areas must be secured with legally enforced waterdischarges during the wet season.

7. The construction of deep reservoirs should be avoided. Deep storage reservoirs are poor with fish and often stratified.

8. Mechanical weeding of aquatic weeds is prefered to chemical weeding.

INTERVENTION: Upstream marsh drainage

| EFFECT - CHAINS | natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| a) location | | | | | |
| peat soils --→ oxidation and compaction of soils } reduction of soil fertility<br>erosion via canals | - | $x^{0,1}$ | $x^{0,1}$ | - | - |
| - loss of wetland habitat | $x^2$ | $x^2$ | - | $x^3$ | - |
| b) water quantity | | | | | |
| - reduction of 'sponge' function of marshes --→ increased peak discharges in rainy period and decreased discharges in dry period | - | $x^2$ | $x^4$ | $x^3$ | $x^4$ |
| c) water quality | | | | | |
| - leaching of agricultural chemicals | $x^5$ | $x^5$ | - | $x^5$ | $x^5$ |
| d) disposition of natural resources | | | | | |
| e) secondary impacts | | | | | |

Alternatives and mitigating measures for
<u>upstream marsh drainage.</u>

0. <u>Inventory of pre-project situation</u>. Take particularly notice of the soil characteristics.
   <u>Alternatives:</u>
   * Drainage of for instance marshy peats causes an irreversible process, by which an intensive, but not sustainable land-use is made possible. Development of these areas should be executed with the greatest reservedness as possible.
   * Development of land utilization types which need only partial drainage (rice-agriculture) should be taken into consideration.

1. Canalbottom drops could prevent a rapid decline of the groundwater level, as to slow down oxidation- and compaction processes. These drops also prevent high stream velocities, which cause canalbank erosion.

3. Valuable parts of the marshes, particularly depressions in the wetlands, which are difficult to drain, should be protected and developed as nature reserves.

3. New kinds of landuse should be developed as a compensation for people who used to exploit the marshes.

4. Downstream structures should be build to prevent undesirable flooding. Water could possibly be stored for dry seasons.

5. Within an integrated weed control program, bio-degradable pesticides should be used.

INTERVENTION: Impoldering (reclamation)

| EFFECT - CHAINS | natural values | sponta- neous functions | intensive exploi- tation | exten- sive ex- ploitation | health |
|---|---|---|---|---|---|
| | target variables | | | | |
| a) location | | | | | |
| - loss of fish- and grazing grounds of wildlife/cattle | – | – | – | x[1] | – |
| - loss of habitat for wildlife/birds | x[1] | x[1] | – | x[1] | – |
| - loss of valuable ecosystems | x[1] | x[1] | – | – | – |
| - risk of acid sulphate soil development (in coastal areas) | – | – | x[2] | – | – |
| - loss of natural fertilization | – | x[8] | x[8] | – | – |
| - blocking of migration routes of people/cattle/wildlife | x[7] | x[7] | – | x[7] | – |
| b) water quantity | | | | | |
| - loss of buffer capacity and sponge function of lakes/wetlands --→ increased peak discharges and risk of downstream flooding | – | x[4] | – | – | x[4] |
| c) water quality | | | | | |
| - water purification capacity of marshes is lost | x[5,6] | x[5,6] | – | x[5,6] | x[5,6] |
| - drainagewater of polder is contaminated with agro-chemicals | x[5,6] | x[5,6] | – | x[5,6] | x[5,6] |
| d) disposition of natural resources | | | | | |
| - the community loses collective control over natural resources --→ social changes, marginalisation, increased pressure on remaining resources (fuelwood, poaching etc.) | x[1,3] | – | – | x[1,3] | |
| e) secondary impacts | | | | | |
| - improved infrastructure means better access to previously isolated areas --→ population increase --→ pressure on resources, need for sanitary facilities | x[9] | x[9] | – | x[9] | x[9] |

Alternatives and mitigating measures for impoldering (reclamation).

0. Inventory of the pre-project situation. Take special notice of the soil-characteristics (acid-sulphate soils, peat), sedimentation processes, fish habitats, grazing grounds for cattle, presence of semi-nomadic farmers and fishermen.
   Alternatives:
   * increase of production on existing agricultural areas
   * more efficient storage and processing of the products (decreasing losses)
   * horse-shoe dikes and other structures to cope with the floods (low-cost solution, as compared with total reclamation)

1. Reclamation projects should be developed, as much as possible, downstream of valuable nature areas and important fishing and grazing grounds. Around these projects nature reserves and bufferzones should be assigned.
   The tradional inhabitants of the project areas should get compensation for their lost farming system.
   A cost-benefit analysis should take into account the loss of fish production and cattle grounds.

2. Before the start of the project, soil research is quite necessary. After reclamation, acid-sulphate soils could develop. The choice for a certain culture should be based on this potential acidity. If leaching of the acids out of the soil cannot effectively be accomplished, reclamation is strongly discouraged.

3. A bottom-up strategy (planning), carried by participating local communities should be implemented. The polder should be developed step by step (in space as well as in time) in order to let the changes pass away gradually and to introduce flexibility.

4. Remaining wetlands should be preserved in order to store an extra amount of water.

5. At the outlets of the polder, reed fields and/or sewage purification installations should be constructed to replace the purification function of wetlands.

6. Bio-degradable pesticides should be used. Fertilizers should be supplied in a limited way.

7. In the project design, corridors should be planned to facilitate migration of cattle and wildlife.

8. Within the new polder, the sustainability of the agricultural activities is the main objective. Fertilizers have to be used, even as other external inputs.
   The feasibility study should compare the new farming system with the original one and should predict the consequences of a growing dependence on external inputs. A study of the carrying capacity of the ecosystem is also necessary in the feasibility-study.

INTERVENTION: Arid-land irrigation with riverwater

| EFFECT - CHAINS | target variables: natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| a) <u>location</u> | | | | | |
| - loss of existing landuse in project area | - | - | - | $x^{0}$ | - |
| - impact on ecosystem | $x^{1,3}$ | $x^{1,3}$ | - | - | - |
| - risk of soil salination | - | - | $x^{2,5}$ | - | $x^{2,5}$ |
| - climatic changes through increased evapotranspiration (local thunderstorms) | - | X | X | - | - |
| b) <u>water quantity</u> | | | | | |
| - regulation of river discharges: reduction of peak discharges and change in timing of the floods | $x^{3}$ | $x^{3}$ | $x^{3,6}$ | $x^{3}$ | - |
| - reduction of peak discharges can lead to a reduction of or complete eradication of wetland acreage downstream (flood-plains, estuaries, mangroves and other wetlands) | $x^{3}$ | $x^{3}$ | - | $x^{3}$ | - |
| c) <u>water quality</u> | | | | | |
| - drainagewater is contaminated with agro-chemicals | $x^{5,8}$ | $x^{5,8}$ | $x^{5,8}$ | $x^{5,8}$ | $x^{5,8}$ |
| - stagnant surface water --- salination, waterrelated diseases, aquatic weeds | - | - | $x^{5,7}$ | | $x^{5,7}$ |
| d) <u>disposition of natural resources</u> | | | | | |
| - commercialization of agriculture and natural resources --- change in disposition of resources --- socio-econ. differentiation / social conflicts --- reduced incentives to safeguard their own environment | - | - | $x^{0,1,2}$ | $x^{0,1,2}$ | $x^{0,1,2}$ |
| e) <u>secondary impacts</u> | | | | | |
| - improvement infrastructure | $x^{2}$ | - | $x^{2}$ | $x^{2}$ | - |
| - stimulus to urban and industrial development | $x^{2}$ | - | $x^{2}$ | - | $x^{2}$ |
| - development aquaculture in canals and reservoirs | | | | | |

Alternatives and mitigating measures for
arid land irrigation with riverwater.

0. Inventory of the pre-projectsituation: take notice of the importance of dry-land agriculture (rainfed) in the tradional mode of production and take notice of womens' role in traditional farming systems.
   Alternatives:
   * development of smaal-scale irrigation
   * development of dry farming systems
   * in case of large-scale projects: use a decentralized management model with optimal participation of farmers' associations instead of a central bureaucratic management

1. Guarantees should be built as to provide every household equal access to safe domestic water, land, credit and living resources, such as cattle, homegardens, fuelwood, timber etc.

2. A diversification of different sources of income should be created: dry farming, cattle-breeding, non-agricultural labour etc, by which more safeguards for a subsistence level are built in and a second generation also can generate an income.

3. Irrigation always causes a decrease of river flows downstream (losses by evapotranspiration). Damage to downstream wetlands should be mitigated by an optimalisation of riverbasin watermanagement or by the construction of flowcontrol structures.

4. An adequate drainage of irrigation water should be ensured, to prevent stagnation and hence salination, waterborne diseases and aquatic weeds.

5. All allotments should get an equal and ensured amount of water, to prevent social conflicts.

6. An environmental management program should be elaborated to fight waterborne and waterrelated diseases.

INTERVENTION: River canalization / normalization

| EFFECT - CHAINS | target variables: natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| **a) location** | | | | | |
| - a by-pass canal is a barrier for cattle and wildlife which in the dry season migrates towards the river and its floodplain | X[1] | X[1] | - | X[1] | - |
| - water flow perpendicular of canal will change --→ lee-side of canal will dessicate | X[1] | X[1] | - | X[1] | - |
| - river normalization (straightening the river banks) will affect the riparian forests | X | X | - | - | - |
| **b) water quantity** | | | | | |
| - wetlands alongside the river parallel to canal will get less water | X[2] | X[2] | - | X[2] | - |
| **c) water quality** | | | | | |
| **d) disposition of natural resources** | | | | | |
| -better transportfacilities giver by the canal increases the chance of poaching | X[3] | X[3] | - | - | - |
| **e) secondary impacts** | | | | | |
| - new settlements along canal --→ overgrazing, health problems | - | - | - | X[4] | X[4] |
| - downstream new opportunities for irrigation | | see 'irrigation' | | | |
| - improved water discharge facilitates wetland drainage | | see 'drainage' | | | |
| - improved navigability lures industry | | | | | |

Alternatives and mitigating measures for
river canalisation and normalisation.

0. Inventory of the pre-project situation: Take special notice of the preservation of mitigation patterns of cattle and wildlife.
   Alternatives:
   * more adequate and eficient water use (reduce waterlosses at canal ends)
   * dredging of river bed
   * increase of waterdischarges through a decrease of evapotranspiration losses in upstream areas (sound watershed management!)
   * soil conservation in upstream areas (less sedimentation)

1. Large bridges could facilitate migration of cattle and wildlife.

2. The old river course need not to be cut off completely. This generates the possibility to partially flood adjoining wetlands when a portion of the peakflow is passed on to the old river course.

3. The lay-out of the canal should avoid destruction of valuable nature areas.

4. If many nomadic ethnic groups exist in the project area, canalisation will cause strong social changes. This may lead to socially unacceptable situations when these people do not profit from the canal development itself. Non-participation may lead to social marginalisation and subsequent over-exploitation of natural resources.

INTERVENTION: Aquaculture development

| EFFECT - CHAINS | natural values | spontaneous functions | intensive exploitation | extensive exploitation | health |
|---|---|---|---|---|---|
| | target variables | | | | |
| a) location | | | | | |
| - loss of natural habitat for fish, birds and wildlife | $x^0$ | $x^0$ | - | $x^0$ | - |
| - in coastal areas risk of acidification due to acid sulphate soils (under mangroves!) and stagnant water | - | - | $x^1$ | - | - |
| b) water quantity | | | | | |
| c) water quality | | | | | |
| - stagnant water --→ waterrelated diseases | - | - | - | - | $x^2$ |
| d) disposition of natural resources | | | | | |
| e) secondary impacts | | | | | |

Alternatives and mitigating measures for
the development of fishculture/aquaculture.

0. Alternatives: * improvement of existing traditional fishing techniques and fish processing

1. The fishponds should be flushed with sufficient brackish water to prevent acidification.

2. Snail control (to prevent bilharsia) and a sound health program should be set up.