Chapter 20

ECONOMIC VALUE OF PRODUCTION SYSTEMS

20. ECONOMIC VALUE OF PRODUCTION SYSTEMS

20.1 SUMMARY OF METHODOLOGY AND FINDINGS

Four alternative scenarios are assessed in terms of their economic impact on downstream values, and compared with the present situation as a baseline[1]:

Flood Release:

- Alternative **MR** Maximum flood and sediment Release[2]
- Alternative **R** Flood and sediment Release

Flood Control:

- Alternative **C:** Flood Control
- Alternative **MC:** Maximum flood Control

The systems that have been included in this assessment are as follows:

Agricultural systems	Fisheries	Wild habitats and species	Urban and rural infrastructure
Pastoralist production	Freshwater fisheries	Wildlife resources	
Flood-recession agriculture	Marine fisheries	Protected areas	Water supplies
Irrigated agriculture	Prawn farming	Forests	Roads and bridges
		Lakes and Wetlands	
		Mangroves	

The project alternatives represent a range of possible scenarios which will have differing impacts on downstream systems, from the best-case scenario of dams implemented with maximum flood release measures (Tana flooding regimes will be reinstated, and downstream systems will actually improve as a result of this), to the worst case scenario of dams implemented with maximum flood control (Tana

[1] This baseline reflects the average hydrological conditions represented by the 25 year flow series used in the hydrological analyses during Phase 2, and includes both drought years and years with above average rainfall and river flow conditions.

[2] It is considered that the proposed dam(s) will have the capacity to improve downstream conditions, namely: minimum flows will be increased, whilst controlled release of artificial floods during the wet seasons also has the capacity to improve downstream conditions from the current situation.

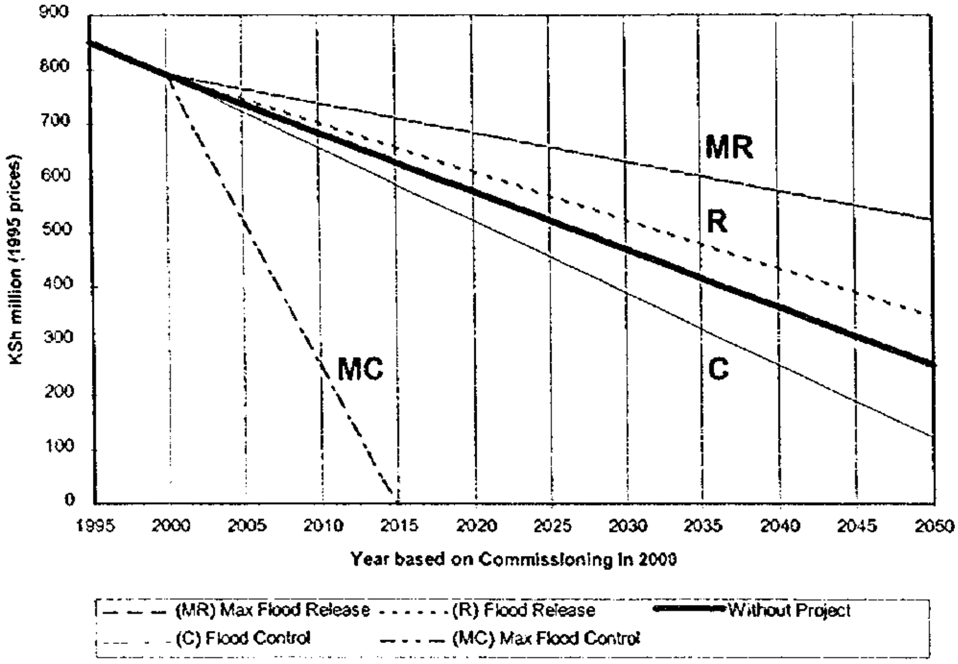
flooding regimes will decrease still further, and downstream systems will be rapidly degraded or destroyed).

These project alternatives are compared to a baseline of the current "without project" situation, of existing dams only. The Tana flooding regime has already been affected as a result of the existing dams, and downstream values have been degraded.

Under a continuation of the present situation, this degradation will progressively worsen. Construction of additional dams without any flood release measures will aggravate and hasten this destruction (alternative C and MC). However, implementation of additional dam construction with flood release measures has the potential to at least partially reverse these negative impacts (alternative R), and at best significantly improve downstream values above the current situation (alternative MR).

These results are presented schematically in Figure 20-1.

Figure 20-1 Trends in Annual Net Value of Downstream Production Systems: with different project options



Therefore, overall, a project implemented with flood release measures implies significant economic benefits in terms of its positive effect on downstream systems and values. With flood control, dam construction will impose a considerable economic cost on already degraded and vulnerable downstream systems.

20.1.1 Time Frame and Discounting

The effects of environmental degradation and improvement are long-term in nature, and dam construction and commissioning involves various phases. For this reason, a stream of future economic values have been calculated over a 50 year time-frame, and discounted in order to give a series of net present values (NPVs) for different project alternatives.

Although it has been argued that lower discount rates should be applied to environmental values, in order to give future environmental costs and benefits a greater present weight and thereby encourage environmentally beneficial projects, for this study the discount rate used (10%) reflects the prevailing opportunity cost of capital in Kenya. This is because it is considered that the discount rate should be the same as that used to appraise other investment projects in Kenya, and that manipulation of the discount rate is not in this case necessary to highlight potential environmental costs and benefits.

It is very difficult to make accurate predictions concerning the rate at which environmental degradation will occur under different scenarios. For simplicity, a standardised time frame has therefore been applied to different project scenarios. Where dam construction is likely to impose costs on downstream systems, it is assumed that these changes will be effected in 100 years in the case of MR, 60 years in R, 50 years without projects, 40 years in C and 10 years in MC[3].

20.1.2 Option and Existence Value

The goods and services supported by the Tana River are wide-ranging and diverse, and encompass direct use values, indirect or ecological values, option values and existence values[4]. It is currently impossible to satisfactorily value all these benefits.

Thus, although it is possible to make estimates of some of the values attached to river-dependent activities and systems, these figures will greatly underestimate the true benefits attached to maintaining the natural hydrological regime of the Tana River[5]. The following estimates should therefore be taken as partial or indicative figures which reflect only a small proportion of the goods and services provided by the river, and provide an example of some of the costs associated with the changes in hydrology resulting from dam construction.

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[3] It is important to note that downstream systems have already undergone certain changes because of factors that are unrelated to dam construction, including drought, insecurity and other infrastructural developments carried out in the area. These changes will continue independently of any proposed dam construction.

[4] Option value is the premium placed on maintaining a resource for future use. Existence value is the intrinsic value of a resource, regardless of actual use; it includes such aspects as cultural and aesthetic value.

[5] The importance of maintaining a flooding regime is emphasised by studies from the Senegal River basin, where reduced flooding following construction of Manantali dam is considered to have had serious economic and social consequences. Other studies, in USA, have resulted in recent plans to initiate controlled flooding from the Hoover Dam. Excessive river engineering and control is thought to have contributed to recent "natural" disasters on the rivers Mississippi and Rhine, and in the latter case efforts are being made to reintroduce a degree of natural flooding in some areas.

20.2 AGRICULTURAL PRODUCTION SYSTEMS

Most of the area surrounding the Tana River lies in low-potential agro-ecological zones L6 and L5 (classified as ranching and livestock-millet zones), with small areas of L4 (coconut-cassava zone) at the southern end of the Delta. Agricultural possibilities are extremely limited and the predominant land-use is pastoralism, with small areas of flood plain farming around the river and in the Delta; some small and large-scale irrigated agriculture is also practised. All these systems depend on water supplied from the Tana River and its flooding regime. The basis for the value assessments are given in the following sections.

Table 20-1 Net Present Value of Agricultural Production Systems (Ksh M)

		Present	M	LGF	LGFM	HGF
Livestock pasture and water	Replacement	1 620	1 535	1 313	1 203	803
Flood plain agriculture	Value	81	77	66	61	42
Irrigated agriculture	Value	1 392	1 392	1 392	1 392	1 392
Total		3 093	3 004	2 771	2 656	2 237

20.2.1 Pastoralist Production

The Tana River provides water for livestock consumption and also supports a number of permanent and dry-season grazing areas. The nomadic and semi-nomadic pastoralist groups who occupy the arid hinterlands of the lower Tana River keep the majority of livestock. Both the Tana River flood plains and the Delta areas, as well as lakes and wetlands fed by the river, are used as a regular and seasonal source of pasture and water by livestock.

The present situation can not be considered as a stable one: the effects of recent droughts, the increasing alienation of traditional grazing areas, and a breakdown in the security situation has decreased the amount of pasture and grasslands available for dry-season grazing and stock watering. For the purposes of this calculation, it is assumed that flood plain and Delta grazing areas have already decreased by a tenth, and will continue to decline to a tenth of their original area over the next 50 years. This constitutes a present cost of Ksh 0.5 billion compared to the past situation.

It has been estimated that up to three quarters of dry season livestock water is supplied by the Tana River. The river forms the only permanent source of water and pasture in the District in times of drought, when herds also enter the area from southern Garissa, eastern Kitui and Lamu. Other sources of water in the District are limited, and include *laghas* originating in Kitui District, pans, reservoirs, water holes and depressions.

As livestock water requirements can be satisfied from other sources in the wet season, the major value of the Tana River is as a source of water and pasture in dry seasons and drought.

If herd composition and differing water requirements are taken into account, the Tana River and Delta flooded areas may supply the equivalent of nearly 4 million cubic metres of water to livestock in dry seasons.

The value of this pasture and water can be calculated by looking at the alternative requirements for feeding and watering livestock in the absence of the resources supported by the flooding of the Tana River and Delta. This would require the provision of additional dry season watering points and pasture areas, which could be achieved at a total cost of just under Ksh 2 billion and would cost up to Ksh 26 million a year to maintain.

The Tana Delta provides approximately 100,000 ha of pasture; non-cultivated areas of the Tana River flood plain may total 250,000 ha. Thus up to 350,000 ha of dry season pasture may depend on the flooding regime of the Tana River. To maintain irrigated grassland in these areas may have a capital cost of Ksh 1.8 billion and an annual cost of Ksh 19 million.

Table 20-2 Dry-Season Livestock Water

	Number of animals	Water used per dry season (10^6 m^3)
Cattle	1 071 000	3.6
Shoats	1 286 000	0.3
Camels	84 000	0.01
Total	2 441 000	3.91

The Situation with Additional Dams

- With additional dam construction without flood release measures, the decrease in dry season grazing and water in the floodplain area which is already occurring will be hastened, and may finally be lost altogether. This may represent a present cost of between Ksh 83-1,333 million.
- With flood release measures, floodplain water and grazing will continue to decline, but at much slower rates than at present, and will not be so

extensively destroyed[6]. This may represent a present benefit of between Ksh 56-168 million.

20.2.2 Flood Recession Agriculture

The Pokomo, Wasonya, Korokoro and Malakote, and a small minority of Orma, practice arable agriculture on the flood plain along the Tana River between Garissa and the Indian Ocean, and depend on the river's bi-annual floods to irrigate their crops and provide soil nutrients.

Cropping patterns are determined by distance from the river. River banks are planted with bananas and sometimes sugar cane; rice is grown on the lower areas behind river banks; and on the higher ground beyond this, maize, cowpeas, green grams and other crops are cultivated. No crop rotation is practised, nor is there any systematic fallowing: the majority of farmers own several plots and plant according to seasonal flooding patterns.

The flood plain occupies a total area of 3,000 km². The mean cultivated areas are approximately 1.5 ha/household and up to two thirds of the directly river and Delta adjacent population may grow arable crops. There may therefore be 23,000 households who cultivate a total area of 34,500 ha and depend on floods from the Tana River to irrigate their crops. This represents just over 10% of the flood plain area, and may support a total population of 115,000 people. An average farm cultivating rice, maize, green grams, cowpeas and bananas may realise net annual returns of Ksh 62,000, and a total of Ksh 14m a year may be contributed by flood plain agriculture.

Recent drought conditions, combined with the effective loss of the east bank of the river to the farming system as a result of a deteriorating security situation has already led to a decline in the viability of the system. Flood plain farmers are becoming increasingly reliant on the smaller floods of local *laghas* to cultivate crops, and are unable to depend on floods to irrigate their crops around the Tana River and Delta. If current crop production is 70% of past harvests, and is assumed to continue to decline to a tenth of current levels over the next 50 years, this represents a present cost of Ksh 58 million.

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[6] The high rate of production in floodplains is certainly an important factor. This is partly due to the high quality of floodplain grass species, which are generally high in fodder quality, containing a relatively high content of crude protein, compared to non-floodplain grasses. They are also highly palatable, even when dry. In contract, non-floodplain grasses loose their palatability on drying. Thus even in regions of similar grass production, floodplain species will always be more attractive to herbivores, and will support greater livestock numbers. A reduction in flood frequency and extent will result in a gradual change from floodplain adapted species to non-floodplain species and thereby an overall reduction in carrying capacity, production and economic benefits. It was proposed during the Public Workshop held at the end of Stage 2 of this study that this aspect be studied in greater detail by a "Parallel Study" which would constitute a more detailed environmental assessment of the downstream aspects.

The Situation with Additional Dams

- With additional dam construction without flood release measures, the frequency of river bank inundation will decline still further, and agricultural possibilities will decrease. This may represent a present cost of between Ksh 4-64 million.
- With flood release measures, the average period between floods may decrease to two floods each year, improving current agricultural production potential. This may represent a present benefit of between Ksh 3-8 million.

20.2.3 Irrigated Agriculture

Both large and small-scale irrigation depends on water from the Tana River. It is estimated that nearly 3,000 ha of irrigated rice and other crops are be cultivated around the Tana River, supporting up to 10,000 people.

Table 20-3 Irrigated Agriculture

	Approximate population supported by planned area	Planned area (ha)	Approximate population supported by current area	Current area (ha)
Hola	3 500	870	0	0
Bura	50 000	6 700	0	0
TDIP	15 000	12 200	250	200
LTVIP	no data	no data	1 250	240
Others	8 500	2 520	8 500	2 520
TOTAL			10 000	2 960

Tana Delta Irrigation Project (TDIP); located in Garsen Division. This will cover up to 16 000 ha if fully completed, and is for mechanised rice production. At present 200 ha are under production.

Lower Tana Village Irrigation Project; has been in operation since 1979. At present there are five village schemes with a total area of 240 ha, and each farmer cultivates approximately 1 hectare. Rice is the major crop grown.

Bura Irrigation Settlement Scheme; presently non-functional, was initiated in 1985 to develop about 6,700 ha of irrigated cotton and food crops and 4,500 ha of fuelwood plantations. The total population of the scheme, when fully implemented, would have been about 50,000 people.

Hola Irrigation Scheme; was started in 1956 and later developed as a tenant scheme with 690 tenants on 870 ha. However, due changes in the course of the Tana River, this scheme has been non-operational since 1989.

In total, there are currently 440 ha of irrigated rice grown in TDIP and LTVIP, and up to 2,520 ha of vegetable crops in other schemes. These may produce net returns of Ksh 140 million a year.

The Situation with Additional Dams

NO VALUES CHANGE

Table 20-4 Annual Returns to Flood plain Agriculture per Ha.

MAIZE		Seed required (Kg/Ha)	20
		Price of seed (Ksh/Kg)	12
Yields (Kg/Ha)	1 350	Total seed cost (Ksh)	240
		Fertiliser required (Kg/Ha)	-
Total Production (Kg/Yr)	1 350	Price of fertiliser (Ksh/Kg)	-
Crop price (Ksh/Kg)	12	Total fertiliser cost (Ksh)	-
Gross income (Ksh/Yr)	16 200	Labour required (Days/Yr)	88
Total costs (Ksh/Yr)	4 640	Price of labour (Ksh/day)	50
Net income (Ksh/Yr)	11 560	Total labour cost (Ksh)	4 400
RICE		Seed required (Kg/Ha)	45
		Price of seed (Ksh/Kg)	27
Yields (Kg/Ha)	1 000	Total seed cost (Ksh)	1 223
		Fertiliser required-SA (Kg/Ha)	250
Total Production (Kg/Yr)	1 000	Price of fertiliser (Ksh/Kg)	19
Crop price (Ksh/Kg)	35	Total fertiliser cost (Ksh)	2 375
Gross income (Ksh/Yr)	35 000	Labour required (Days/Yr)	150
Total costs (Ksh/Yr)	7 348	Price of labour (Ksh/day)	50
Net income (Ksh/Yr)	27 652	Total labour cost (Ksh)	3 750
COWPEAS		Seed required (Kg/Ha)	15
		Price of seed (Ksh/Kg)	35
Yields (Kg/Ha)	630	Total seed cost (Ksh)	525
		Fertiliser required (Kg/Ha)	-
Total Production (Kg/Yr)	630	Price of fertiliser (Ksh/Kg)	-
Crop price (Ksh/Kg)	35	Total fertiliser cost (Ksh)	-
Gross income (Ksh/Yr)	22 050	Labour required (Days/Ha/Yr)	47
Total costs (Ksh/Yr)	2075	Price of labour (Ksh/day)	50
Net income (Ksh/Yr)	19 175	Total labour cost (Ksh)	2 350
GREEN GRAMS		Seed required (Kg/Ha)	15
		Price of seed (Ksh/Kg)	35
Yields (Kg/Ha)	315	Total seed cost (Ksh)	525
		Fertiliser required (Kg/Ha)	-
Total Production (Kg/Yr)	315	Price of fertiliser (Ksh/Kg)	-
Crop price (Ksh/Kg)	35	Total fertiliser cost (Ksh)	-
Gross income (Ksh/Yr)	11 025	Labour required (Days/Yr)	47
Total costs (Ksh/Yr)	2 875	Price of labour (Ksh/day)	50
Net income (Ksh/Yr)	10 500	Total labour cost (Ksh)	2350
BANANAS		Stems required	50
Planted area (stems)	50	Price of stems (Ksh/stem)	negligible
Yields (Kg/stem)	15	Total stem cost (Ksh)	0
No. harvests/year	-	Fertiliser required-FYM (Kg/stem)	0.01
Total Production (Kg/Yr)	750	Price of fertiliser-FYM (Ksh/Kg)	31
Crop price (Ksh/Kg)	12	Fertiliser required-ASN (Kg/stem)	0.08
Gross income (Ksh/Yr)	9 000	Price of fertiliser-ASN (Ksh/Kg)	34
Total costs (Ksh/Yr)	832	Fertiliser required-DSP (Kg/stem)	0.15
Net income (Ksh/Yr)	8 168	Price of fertiliser-DSP (Ksh/Kg)	24
		Total fertiliser cost (Ksh)	332
		Labour required (Days/Yr)	10
		Price of labour (Ksh/day)	50
		Total labour cost (Ksh)	500

Table 20-5 Annual Returns to Irrigated Agriculture per Ha.

RICE		Seed required (Kg/Ha)	45
Yields (Kg/Ha)	5 000	Price of seed (Ksh/Kg)	27
		Total seed cost (Ksh)	1 215
Crop price (Ksh/Kg)	15	Fertiliser required (Kg/Ha)-SA	250
Gross income (Ksh/Ha)	75 000	Price of SA (Ksh/Kg)	19
		Total fertiliser cost (Ksh)	4 750
		Labour required (Days/Yr)	100
Total costs (Ksh/Ha/Yr)	23 965	Price of labour (Ksh/day)	50
Net income (Ksh/Ha/Yr)	51 035	Total labour cost (Ksh)	5 000
		Diesel required for pumps/tractors (Litres/Ha)	480
		Cost of diesel (Ksh/Litre)	25
		Total diesel cost	12 000
		Discounted equipment cost (Ksh/ha)	1 000
TOMATOES		Seed required (Kg/Ha)	0.15
Yields (Kg/Ha)	12 500	Price of seed (Ksh/Kg)	55
		Total seed cost (Ksh)	8
Crop price (Ksh/Kg)	6	Fertiliser required (Kg/Ha)-FYM	250
Gross income (Ksh/Ha)	75 000	Price of FYM (Ksh/Kg)	31
		Total fertiliser cost (Ksh)	7 750
		Labour required (Days/Yr)	100
Total costs (Ksh/Ha/Yr)	16 258	Price of labour (Ksh/day)	50
Net income (Ksh/Ha/Yr)	58 742	Total labour cost (Ksh)	5 000
		Diesel required for pumps/tractors (Litres/Ha)	100
		Cost of diesel (Ksh/Litre)	25
		Total diesel cost	2 500
		Discounted equipment cost (Ksh/ha)	1 000
ONIONS		Seed required (Kg/Ha)	2
Yields (Kg/Ha)	8 800	Price of seed (Ksh/Kg)	45
		Total seed cost (Ksh)	90
Crop price (Ksh/Kg)	7.5	Fertiliser required (Kg/Ha)-DSP	200
Gross income (Ksh/Ha)	66 000	Price of DSP (Ksh/Kg)	24
		Total fertiliser cost (Ksh)	4 800
		Labour required (Days/Yr)	100
Total costs (Ksh/Ha/Yr)	13 390	Price of labour (Ksh/day)	50
Net income (Ksh/Ha/Yr)	52 610	Total labour cost (Ksh)	5 000
		Diesel required for pumps/tractors (Litres/Ha)	100
		Cost of diesel (Ksh/Litre)	25
		Total diesel cost	2 500
		Discounted equipment cost (Ksh/ha)	1 000
KALES		Seed required (Kg/Ha)	-
Yields (Kg/Ha)	9 000	Price of seed (Ksh/Kg)	-
		Total seed cost (Ksh)	-
Crop price (Ksh/Kg)	5	Fertiliser required (Kg/Ha)-SA	200
Gross income (Ksh/Ha)	45 000	Price of SA (Ksh/Kg)	19
		Fertiliser required (Kg/Ha)-DSP	150
		Price of DSP(Ksh/Kg)	24
Total costs (Ksh/Ha/Yr)	15 900	Total fertiliser cost (Ksh)	7 400
Net income (Ksh/Ha/Yr)	29 100	Labour required (Days/Yr)	100
		Price of labour (Ksh/day)	50
		Total labour cost (Ksh)	5 000
		Diesel required for pumps/tractors (Litres/Ha)	100
		Cost of diesel (Ksh/Litre)	25
		Total diesel cost	2 500
		Discounted equipment cost (Ksh/ha)	1 000

20.3 FISHERIES

20.3.1 Commercial and Subsistence Fisheries

The lower Tana basin supports a number of fisheries activities, changes in river flow, and in particular flood flow, will affect the productivity.

Table 20-6 Net Present Value of Fisheries (Ksh M)

		Present	M	LGF	LGFM	HGF
Commercial freshwater	Value	61	59	54	51	42
Subsistence freshwater	Value	175	169	153	145	121
Commercial marine	Value	19	18	17	17	15
Prawn farms	Value	2,555	2,482	2,300	2,218	1,935
Total		2,810	2,728	2,524	2,431	2,113

Although few households depend on fishing as their sole source of subsistence or livelihood, the Tana River supports both subsistence and commercial fisheries, which are an important source of domestic protein and income for surrounding households.

Table 20-7 Fisheries Supported by The Tana River

	Main groups dependent on system	Approx. no. people dependent on system	Annual value of system (Ksh M)
Commercial freshwater fisheries	Luo, Luhya	3,600	7.8
Subsistence freshwater fisheries	Pokomo, Bajun	50,000	22.3
Commercial marine fisheries	Giriama, Swahili	800	2.3
Prawn farms	Private companies		104
	TOTAL	54,400	136.4

Subsistence fishing is practised by just over a third of non-pastoralist households living near the Tana River and Delta and nearby lakes and wetlands. This would indicate that around 10,000 households, engage in subsistence fisheries. Based on an average of 3 trips and 7 fish a trip, assuming an average weight of 0.1 kg, then the total annual catch could be 1,000 tonnes, with a 1994 value of Ksh 22.3 million a year.

Commercial freshwater fishing is primarily focused on the ox-bow lakes in the Delta. It is estimated that approximately 2% of the river and Delta population engage in commercial fisheries. The volume and value of commercial freshwater fisheries is at present around 350 tonnes per year with a value of Ksh 7.8 million

Marine fisheries are carried out in the mangrove swamps of the Tana Estuary and Delta and the Indian Ocean. Commercial marine fisheries in the area of the Indian Ocean directly bordering the Tana Delta contributed a 1994 value of Ksh 2.3 million in 1990, with a total catch of nearly 50 tonnes of fish and crustaceans[7].

There have already been decreases in fisheries that can be attributed to changes in the riverine and delta environment. In particular, as a result of river diversion for irrigation, the fisheries in Lakes Bilisa and Mlango have declined. It is assumed that freshwater fisheries have declined by one tenth, and will eventually decline to a quarter of their original levels over the next 50 years. Marine fisheries may, over the same period, drop to half their present levels. This represents a present cost of Ksh 67 million as compared to the past situation.

The Situation with Additional Dams

- With additional dam construction without flood release, continued changes in flooding and sedimentation will hasten the current decline of river-dependent and wetland fisheries, and changes in the Delta area will lead to a decline in marine catches as fish yields decline. This may represent a present cost of between Ksh 10-156 million.
- With flood release measures, some riverine and wetlands fisheries will be re-established, and the decline in fisheries yields will be slowed. This may represent a present benefit f between Ksh 7-20 million.

20.3.2 Prawn Farms

There are three operating or planned prawn farms in then area around the Tana Delta[8]. These rely on prawn larvae collected from mangrove swamps, and mature these in a series of ponds into which water is pumped from the sea; harvesting is carried out after two months. Earning a net income of over 208,000 Ksh/ha (based on the estimated 1991 prices), existing commercial prawn fisheries may be worth over Ksh 285 million a year at 1994 prices.

There has already been a degeneration of the mangrove ecosystem, as a result of increased extraction of timber, which will have decreased the supply of prawn larvae. It may be assumed that prawn farming will, over the next 50 years, decline to half of

[7] This is likely to be an underestimate, as the offshore trawled catch is primarily landed at Mombassa, with no records available of the amount directly attributable to the area off the Tana Delta.

[8] Fisherman's Choice Prawn Farm is situated near the sea at the boundary between Tana River and Kilifi Districts. It currently occupies an area of 500 ha, and has applied for an additional area of 1,000 ha. Freehold Investments Company has had a proposal approved to start a 150 ha shrimp farm, and Inter-Systems Ltd has been allocated 2,000 ha.

its present levels, because of lack of larvae. This represents a present cost of Ksh 270 million.

Table 20-8 Semi-Intensive Prawn Farming System

Yield (Kg/ha)	1,800	Postlarvae costs	72,000
Price (Ksh/kg)	300	Feed costs	108,000
		Labour costs	24,000
Gross income (Ksh/Ha)	540,000	Fuel costs	21,600
		Pesticide, lime and fertilisers costs	1,800
Total costs (Ksh/ha)	341,320	Maintenance costs	11,370
		Depreciation	82,550
Net income (Ksh/ha)	208,680	Interest on capital	20,000

The Situation with Additional Dams

- The effects of additional dam construction without flood release will be a further decrease in the flushing out effect of flooding, leading to a further decrease in the nutrient load. This will further degrade mangrove systems (see below) and yields of prawn larvae will decline. This may represent a present cost of between Ksh 68-1100 million.
- With flood release measures, the supply of prawn larvae may actually improve over the current situation, although mangroves will continue to be degraded. This may represent a present benefit of between Ksh 46-137 million.

20.4 WILD HABITATS AND SPECIES

A range of habitats and vegetation types are found along the Tana River, which contain a high level of biodiversity, and host several rare, endemic and endangered plant and animal species. There is no duplication of the Tana River ecosystem in East Africa, which makes it a unique natural resource.

Table 20-9 Net Present Value of Wild Habitats and Species (Ksh M)

		Present	M	LGF	LGFM	HGF
Subsistence Hunting	Value	240	235	221	212	187
Forest Utilisation	Value	64	50	48	42	40
Mangrove Utilisation	Value	5	5	4	4	3
Total		295	288	267	256	222

20.4.1 Protected Areas

There are a number of existing and planned protected areas lying alongside the Tana River and Delta. These provide the habitat to a range of plant, bird and animal species some of which are rare, threatened or endangered.

- **Meru National Park** Was gazetted in 1966 and covers an area of 870 km^2. The rivers and evergreen vegetation within the Park provide an important resource for local wildlife, and the Park is an important area for antelope conservation, also containing threatened populations of grater Kudu and Grevy's Zebra.
- **Kora National Park** Was gazetted in 1989, and covers an area of 1,787 km^2.
- **Arawale and Rahole National Reserves** Both these reserves were gazetted in 1974, covering areas of 533 and 1,270 km^2 respectively. The latter is an area important for antelope conservation, in particular it contains a population of 500 of the threatened Hunter's Hartebeest.
- **Tana River National Primate Reserve (TRNPR)** TRNPR was gazetted in 1976 to protect areas of riverine forest and endangered primate species.
- **Tana Delta National Wetlands Reserve** Approximately 312 km^2 of the Tana Delta wetlands were proposed as a conservation area in 1982, with the aim of protecting habitats and their wildlife, and developing tourism.

The effect of the proposed dams is likely to have little impact on the main park areas of Meru, Kora, Arawale and Rahole, all of which are predominantly savannah and bushland areas. However the impact of changes in flow regimes will affect the primate reserve and the wetlands reserve.

A range of wild animal species are found in and around the Tana River and Delta, several of which are rare, endangered or endemic. Some of these animals also constitute an important source of protein for surrounding populations. Riverine hunting is carried out by the Pokomo; game species include antelope, hippopotamus and crocodile.

Although no data is available concerning the incidence or frequency of subsistence hunting, studies in nearby coastal areas have found that approximately 37% of local households regularly engage in hunting activities, catching approximately 100 kg of bushmeat a year at a net value of 34.5 Ksh/kg of meat. For the 23,000 agricultural households who live by the Tana River, the annual value of hunting may therefore be as high as Ksh 29.4m.

Competition between an expanding human population and wildlife species for use of water and riverine habitats has led to a decline in riverine vegetation and habitat, leading to a decrease in animal species.

The Situation with Additional Dams

- The continued loss of riverine and forest vegetation and resulting decline in animal populations and hunting yields will be exacerbated by additional dam construction without flood release measures. This may represent a present cost of between Ksh 6-90 million.
- With flood release measures, this decline will be slower, and some riverine and forest vegetation may be re-established. This may represent a present benefit of between Ksh 4-11 million.

20.4.2 Forest Areas

Areas of riverine forest are found within the TRNPR, along the main river channel, beside tributary channels in the lower part of the Delta and at Mbalambala, Bura, Kipende, Maroni, Makere, Mnazini, Bubesa, Hewani and Wema. There are 3,658 ha of riverine forests lying near to the Tana River, and up to 1,700 households live within 3 km of these forests and use them for various timber and non-timber resources.

The main forest products taken for subsistence purposes include fuelwood, building poles, and palm fronds for thatch, mats and baskets. Canoes are carved from mature canopy trees. The use of plant and tree-based medicines and collection of wild fruits is widespread, and forests are also used for burial and other sacred rituals.

There is little immediate data available on the volume and incidence of subsistence use of forest products around the Tana River. However, based on values from other forest areas, it is possible to make some estimates of the value of this use, which may have a net worth of Ksh 6.5 million a year to adjacent households. Continued pressure from human populations will lead to further losses with or without dam construction.

Table 20.10 Subsistence Use of Forest Resources

FOREST ACTIVITY	NUMBER OF HOUSEHOLDS	UNITS USED PER YEAR	NET VALUE PER UNIT	TOTAL VALUE (Ksh '000)
Fuelwood	880 (52%)	2 993 Kg	1.1 Ksh	2 839
Saplings	813 (48%)	51	54.8 Ksh	2 272
Poles	813 (48%)	8	45.8 Ksh	297
Palm fronds	813 (48%)	96	5.5 Ksh	429
Canoes	508 (30%)	0.24	1 400 Ksh	170
Honey	508 (30%)	17.5 kg	50.7 Ksh	450
Beehives	508 (30%)	0.24	55.6 Ksh	7
			TOTAL	6 464

The Situation with Additional Dams

- The continued decline in overbank flooding and resulting decrease in riverine forest productivity and diversity will be exacerbated by additional dam construction without flood release measures, and the amount and range of forest products available for use will decrease. This may represent a present cost of between Ksh 2-32 million.
- With flood release measures, this decline will be slower, and some forest vegetation may be re-established. This may represent a present benefit of between Ksh 1-4 million.

20.4.3 Freshwater Wetlands

The Tana Delta constitutes a large area of wetland, and there are a number of permanent and temporary lakes and swamps fed by the Tana River.

These freshwater wetlands provide a number of benefits, some of which are reflected in the value of water, grazing and fisheries. As well as supporting bird, animal and fish populations and maintaining biodiversity, many also serve as dry-season grazing areas and provide plant and animal resources for human use. Wetlands provide a number of ecological services, including flood mitigation, prevention of intrusion of saline waters, storm protection, sediment, nutrient and toxicant removal, groundwater discharge and recharge and erosion mitigation.

The Situation with Additional Dams

- It is likely that wetlands areas will continue to decline more rapidly if additional dams are built. These changes are reflected in the economic losses associated with fisheries and wildlife catches.

20.4.4 Mangroves

Mangroves yield a range of direct use values, including fuelwood, charcoal and construction materials. However their major value lies in the ecological services they provide, including coastal protection, regulation of salt intrusion inland, flood and erosion mitigation, sediment removal, carbon store, storm protection and habitat for birds, fish, crustaceans and molluscs.

It has been estimated that the extractive forestry value of mangroves in Kenya yields a net income of Ksh 211/ha/yr, fisheries inside the estuary of Ksh 7,480/ha/yr and mangrove-dependent fisheries outside the estuary of 5 Ksh/ha/yr at 1994 prices. Excluding fisheries values, which are estimated above, for the 2,695 ha of mangroves around the Tana Delta, direct use represents an annual value of Ksh 569,000. Continued competition for wetland resources for conversion to other uses and continued exploitation for timber will lead to continued degradation and loss of the mangrove resources.

The Situation with Additional Dams

- With additional dams without flood release measures. flooding and sediment will decline still further and more rapidly, exacerbating and hastening mangrove degradation. This my represent a present cost of between Ksh 10 000-150 000.
- With flood release measures, this degradation will be slower and less widespread. This may represent a present benefit of between Ksh 10 000-20 000.

20.5 URBAN AND RURAL INFRASTRUCTURE

There are two main aspects related to river flow that effect urban and rural infrastructure. Water supply, for domestic and industrial use, is taken both directly from the river. Damage to road and bridge structures occurs during periods of major flooding.

Table 20-11 Net Present Value of Infrastructure (Ksh M)

		Present	M	LGF	LGFM	HGF
Domestic Water	Replacement	1,430	1,370	1,221	1,143	922
Urban Water	Replacement	584	559	499	467	376
Road Damage	Replacement	(48)	(48)	(48)	(48)	(48)
Total		1,966	1,881	1,672	1,562	1,250

20.5.1 Water Supplies

The majority of the river-adjacent population in Tana River District depend on the Tana River for water, which is the only reliable and permanent water source in the region. Apart from agricultural use, described previously, there are three main ways in which people use this water: for domestic, urban and industrial consumption.

Table 20-12 Water demand in Tana River and Garissa Districts

	Water demand (m^3/day)			
	RURAL	**URBAN**	**INDUSTRIAL**	**TOTAL**
Tana River District	3,072	2,127	149	**5,348**
Garissa District	3,679	9,307	209	**13,195**
TOTAL	6,751	11,434	358	**18,543**

Domestic water is obtained directly from the river, and from dams, wells, boreholes, natural depressions and *laghas*. There are 110 boreholes in Garissa District and 25 boreholes in Tana River District, most of which are located in villages along the river. All of these water sources except *laghas* depend on the Tana River or its associated water table[9].

There are 180,000 people living in the river-adjacent area, and it can be assumed that at least a quarter of them directly or indirectly obtain their domestic water supply from the Tana River through the river itself, piped supplies and dependent wells and water sources. Nearly half a million cubic metres of river water may be used for domestic

[9] Data from wells and boreholes to show the relationships between river water table and groundwater table are not available and long-term observation will be required to identify these relationships (e.g. a minimum of two complete hydrological years). It is proposed that this survey will be carried out as a part of the "Parallel Study" recommended by the Public Workshop. However, in the absence of evidence to the contrary and following the known impacts of dams elsewhere, it should be assumed that boreholes and wells are linked to groundwater recharge by the Tana River.

purposes each year, of which a half may originate from ground and surface water sources which depend on the flooding regime of the Tana River.

In addition to this, piped and unpiped water from the Tana River supplies over 20 towns and market centres in Tana River, Garissa and Lamu Districts. Assuming that urban and industrial water use is double that of domestic demand on a per capita basis, water use over basic domestic requirements may be an additional 300,000 cubic metres a year in the major river-adjacent towns of Hola, Garissa, Garsen, Bura and Madogo, of which a third may originate from ground and surface water sources which depend on the flooding regime of the Tana River.

Therefore, a total of 350,000 cubic metres of water from ground and surface water sources which depend on the flooding regime of the Tana River may be used for domestic, urban and industrial human consumption each year. The cost of purchasing water in outlying areas is Ksh 15 per 20 litre jerrycan, meaning that the value of this water may be the equivalent of Ksh 262.5 million a year.

The Situation with Additional Dams

- With additional dams without flood release, non-river water supplies will continue to decline faster, particularly away from the immediate river channel and groundwater and surface water resources will further dry up. This may represent a present cost of between Ksh 81-1 300 million.
- With flood release measures, some of these water sources will be maintained or re-established, representing a present benefit of between Ksh 55-163 million.
- It should be noted that the impact of the reservoir on local and downstream water quality has not been determined.

20.5.2 Roads and Bridges

There are few major roads in the riverine area of Tana River District. The main road, the A3, runs from Thika westwards through Garissa and on to the north east of Kenya. The other major road, the B8 runs approximately north-south from near Garissa, through Hola, Garsen and on to Malindi. In the Delta area, there are two main roads: the B8, mentioned above, and the C112 running east from Garsen through Witu to Lamu. There are also numerous dirt tracks, which are severely affected by flooding.

There are a total of 1,500 km of roads in Tana River District, and approximately 600 km of gravel and earth roads run beside the river and Delta in Tana River, Garissa and Lamu Districts, and are subject to severe flooding.

If it assumed that roads running alongside the river are subject to major flooding every 5 years which necessitates their improvement, and are severely flooded every 10 years and have to be re-established, this represents a present cost of Ksh 275 million.

Table 20-13 Costs Of Improving And Re-Establishing Gravel And Earth Roads (Ksh per Km)

	Re-establishment	Improvement
Labour	185,000	74,000
Gravel and materials	60,000	24,000
Small tools	5,000	2,000
Mechanical equipment	50,000	20,000
Running costs for equipment	85,000	34,000
Supervision	50,000	20,000
Miscellaneous	65,000	26,000
TOTAL	500,000	200,000

The Situation with Additional Dams

NO VALUES CHANGE

20.6 THE DOWNSTREAM ECONOMIC COSTS AND BENEFITS OF DAM CONSTRUCTION

20.6.1 Quantifiable costs

It is clear that many of the existing production systems are under pressure from existing developments, both upstream and within the lower Tana basin, and will decline in productivity with or without dam construction. However, the incremental cost of building additional dams is high, and it is necessary to offset these costs against the quantifiable benefits of electricity generation resulting from building hydropower schemes.

It is likely that the quantifiable costs of dam construction only constitute a small part of total costs in comparison with unquantifiable costs, outlined below.

20.6.2 Unquantifiable Costs

20.6.2.1 Livelihoods and Social Costs

The vast majority of local populations depend on the Tana river and its flooding regime for their livelihoods. It is impossible to quantify the disbenefits that dam construction may imply in terms of social change and the loss of people's livelihoods.

As a result of increasing population pressure, alienation of community land resources and the effects of the recent drought, arable and livestock production possibilities have become significantly more limited, and there is a high level of dependence on food aid because agricultural production and income is inadequate. Decrease in watered areas has led to increased competition between irrigators and other farmers and pastoralists, and this pressure and conflict has been exacerbated by increasing the sedentarisation of human populations in areas of water availability. Overall, it is likely that additional dam construction will hasten the irreversible processes of pauperisation, destitution and conflict.

Table 20-14 Net Present Value Different Project Alternatives (Ksh M)

	Best Case	Slight Improvement on Present	Present Situation	Slight Decline on Present	Worst Case
Agriculture	1,863	1,766	1,707	1,620	310
Fisheries	2,962	2,858	2,806	2,728	1,568
Wild Habitat and Species	305	295	290	282	169
Infrastructure	2,182	2,073	2,019	1,938	723
Total	7,332	6,993	6,821	6,568	2,770
Change to Present	+ 511	+ 172		- 253	- 4,051

20.6.2.2 Ecological Values

The area around the Tana river is high in biodiversity and contains a number of rare, endangered and endemic plant and animal species. In addition to this, the Tana ecosystem constitutes a unique resource as the only permanent water source in a large arid area. Loss of the natural hydrological regime of the river will destroy species and habitats which cannot be replaced, and may be unable to be replicated *in-situ* elsewhere.

20.6.2.3 Option and Existence Values

Degradation of the Tana River ecosystem also precludes a range of future uses and users, and constitutes a cost in terms of lost option values. Aspects of the system also provide intrinsic existence values to a range of groups, including aesthetic, cultural and heritage benefits. Changes which have been set in place by dam construction may also destroy, or significantly decrease, these values.

20.6.2.4 Mitigative Measures

Overall, it may be concluded that existing dam developments on the Tana River have imposed a significant cost on downstream systems, and that these changes will be exacerbated and hastened by further dam construction. Unless mitigative measures are built into any new dam proposals, there is a real danger that a range of economic benefits will be irreversibly destroyed, constituting a significant, and largely unquantifiable, economic cost on downstream systems and populations.

Section 5

FLOOD & SEDIMENT RELEASE

Chapter 21

FLOOD & SEDIMENT RELEASE: LITERATURE REVIEW

21. FLOOD AND SEDIMENT RELEASE: LITERATURE REVIEW

21.1 SUMMARY

Throughout the world floodplains form a highly productive and yet inherently fragile component of the environment, providing a niche in which certain species and habitats have evolved, and in which farming systems have adapted to natural flooding patterns. In some years floods will not occur, in other years the floods will be excessive, destroying farms and settlements.

As a result of the perceived problem of flood damage, attempts have been made to regulate rivers to stop flood damage. Paradoxically, the more successful these attempts, the more damage has occurred, for although the frequency of flood events is reduced, farming systems and settlement patterns develop that no longer incorporate risk avoidance strategies whilst at the same time the considerable benefits of smaller regular floods are lost. The high population growth rates that typify tropical and sub-tropical countries have encouraged permanent settlement in these flood plains, as if they were no longer at risk from floods, and as a result when the unavoidable random one in a hundred year flood occurs, there is a major catastrophe.

The upstream development of dams, most commonly for hdyropower, irrigation and water supplies, has similarly tended to ignore downstream flooding requirements and failed to control downstream flood damage.

From this review of the literature on existing and proposed reservoir management, there are one or two cases where these concepts of flood release have been considered, and even fewer where any attempt was made to implement flood release. In March 1996, an artificial flood release was carried out by the Glen Caynion dam on the Colorado river in USA as an experiment to improve the present deterioration of downstream environmental condition.

Flood Release Planned and Implemented	e.g. the Colorado river in USA, the Glen Canyon dam. Artificial flood release of 1,300 m^3/sec peak discharge, totalling 900 million m^3 for one week in March 1996 as an experiment to improve the present deterioration of downstream environmental condition.
Planned for Flood Release, Never Implemented	e.g. developments on the Sokoto River in Nigeria, although the benefits of downstream flood dependent systems were recognised, by the time final designs were completed, deliberate flooding management had been abandoned in the face of other requirements such as maximising hydropower;
Built for Flood Release, Inadequately Implemented	e.g. developments above and below the Kafue Flats in Zambia, final designs included flood release, however the planned amount and management was inadequate and the system largely collapsed;

Modified for Flood Release, Changed Management Objectives	e.g. the Pongolo River in South Africa, where following a failure to develop irrigation, management was changed to include specific flooding requirements for downstream communities;
Sediment Release, for Reservoir Management	This has effectively only ever been attempted to protect dam structures, not for downstream benefits. e.g. the proposed sediment release from the Three Gorges Reservoir in China to protect turbine operation will only clear sediment within one hundred metres of the dam wall, initially trapping over 70% of all sediments.

As a result there are no examples where the positive benefits of regular flood release on the environment can be assessed, only the negative effects of halting the natural flooding cycle. These have been shown to include widespread disruption of the floodplain environment and the communities that have evolved systems dependent on natural flood cycles. The benefits of upstream development have been at an often considerable social and environmental cost to the downstream systems and communities and there has been little or no attempt at mitigation or compensation for these losses. In most cases this mitigation could only be done through the deliberate management of flood and sediment release to replicate a degree of natural flooding conditions.

Recently, in the face of widespread recognition of the potentially damaging effects of major development projects, all major donor agencies and many national countries have enacted legislation to ensure that environmental and social development considerations are included as an explicit component of such projects. In addition, it is the direct responsibility of the financing agency and those responsible for implementing the programme to show that due consideration has been paid to environmental concerns.

The concept of environmental tradeoffs has resulted from the acceptance among environmentalists and engineers that there are arguments on both sides of the development equation. The serious negative environmental impacts of large water projects have been clearly demonstrated, but so have the environmental and social benefits. The increasing demand for energy will have to be met by increased generating capacity; the increasing demand for water will have to be met by increasing storage capacity; and hydropower through the development of reservoirs provides a renewable and relatively low polluting energy source.

If potential negative environmental and/or social impacts are identified at the start of a programme, there is then the possibility of negotiating mitigation through alternative or additional developments as part of the overall hydropower programme. The early negotiation of tradeoffs will avoid delays in project implementation and, in the long term is likely to reduce overall project costs. Environmental tradeoffs can include both mitigatory development within the project area and parallel development outside the project area.

21.2 INTRODUCTION

Periodic floods occur naturally on many rivers, forming an area known as the flood plain. However, for the purposes of this study, floodplains are defined as areas which are prone to ***regular seasonal flooding***, rather than irregular flood events. The mechanism that produces this environment is effectively the same throughout the world: a major seasonal variation in river flow caused by either local or upstream climatic patterns. Overbank flow may be either the sole cause of flooding, or supplemented by local rainfall. Riverine floodplains occur in both tropical and temperate zones. In temperate zones flooding is related to both seasonal rainfall patterns and in colder climates to spring snow melt. The river system is often confined between natural levees as it passes through the floodplain, caused by the rapid deposition of course sediments as the river overtops the banks. Floodplains have always provided unique niche habitats, and have been exploited for agricultural uses throughout the world.

In many cases the attempted management of flood plains has been limited to trying to prevent the irregular large, and often economically damaging flood events. There has been a long history of attempts to control floods: the methods are still largely unchanged and include the construction of levees, dams, reservoirs, and floodways and, more recently, reforestation[1].

The Chinese built levees to raise the banks of the Huang He on the supposition that the confined river would then deepen its channel to contain the maximum flow. The result, however, was a raising of the riverbed, because the sedimentary deposit of alluvial soil previously distributed over the entire flood plain during annual flooding was confined to the river bottom. In 4,000 years the level of the river rose as high as 20 m above the surrounding plain. In 1887 one of the worst floods in recorded history occurred when the Huang He broke through the levees, killing more than a million people. Levees were constructed during the Middle Ages on the Po, Danube, Rhine, Rhone, and Volga rivers and have been supplemented recently with reforestation and storage reservoirs.

However, so far despite modern engineering resources, no major flood control works have proved to be totally effective. As population pressure increases, the intensity of rural and urban land use within the floodplain also grows. The result is that when the

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[1] Following increasingly regular flooding of the Mississippi River, scientific research into the causes of floods showed that the construction of levees was insufficient as a method of control, and the first steps were made to provide for reforestation and soil conservation. In 1935 the Soil Conservation Service was established by the Congress of the United States under an act declaring a policy of permanent provision for control and prevention of soil erosion, and for control of floods.

inevitable uncontrollable large floods do occur[1], there is the risk of major damage and loss of life. To some extent this is also the result of a general failure of communications between, on the one hand those agencies involved in administering rivers and adjacent lands, and on the other hand the wide range of specialist skills required to fully understand the nature of the floodplain environments. The inevitable result of such lack of an overall understanding is likely to be a series of short-term or stop-gap measures that are destined to fail in the longer term.

In recognition of this problem, recent proposals for flood control on the Ganges, Brahmaputra and Meghna rivers in Bangladesh, have focused on the managed release of floods onto adjoining floodplains areas, rather than trying to constrain the entire flow through a system of embankments that would have to be constructed for the length of the river system (Brammer, 1990). This management concept includes the release of ***normal floods*** to which the farming systems have evolved. Clearly this release would reduce flow volumes and would be in addition to traditional engineering approaches to flood protection for the major cities.

Flood control therefore becomes the management of the floodplain, which in turn implies the maintenance of regular flooding patterns which in themselves form a component of the mechanism for managing the irregular major damaging flood events (McCully 1993).

21.2.1 Awareness of Environmental Issues

The most comprehensive review of the impact of dams and dam construction has been the three volume study "The Social and Environmental Effects of Large Dams" (Goldsmith and Hildyard, 1984,1986 and 1992), commissioned by the European Ecological Action Group. The study stated that

> **"...big dams and water projects have not only failed to achieve those basic objectives (clean power, reduced flood damage and increased food production through irrigation) but are also leaving a legacy of unsurpassed cultural destruction, disease and environmental damage".**

The study has generated considerable discussion, particularly with reference to the impacts of alternative options to major dams in terms of energy production and water supply. Although clearly not universally accepted as a valid interpretation of costs and benefits of dam construction, in either economic, social or environmental terms, the study has ensured that the potential negative impacts of dam construction are at least better understood by planners, even if outweighed by the positive benefits.

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[1] Recent catastrophic floods during July 1997 on the River Oder in Poland, Check Republic and Germany are a case in point. These have caused vast damage to an economically weak region of small farmers. Although figures for the total damage are not yet available, the World's biggest re-insurance company, Munich Re, predicted that the floods in central Europe could result in damage of more than DM 10 billion.

The most frequently quoted and obvious problems are related to the loss of land in the area of inundation, resulting in the involuntary resettlement of displaced populations, with associated economic social and cultural costs, and to the destruction of habitat within the reservoir and surrounding areas. Additional problems are associated with the increase in water related disease vectors (particularly malaria, schistomiasis, filariasis and onchocerciasis) in areas adjacent to reservoirs and within newly established irrigation schemes.

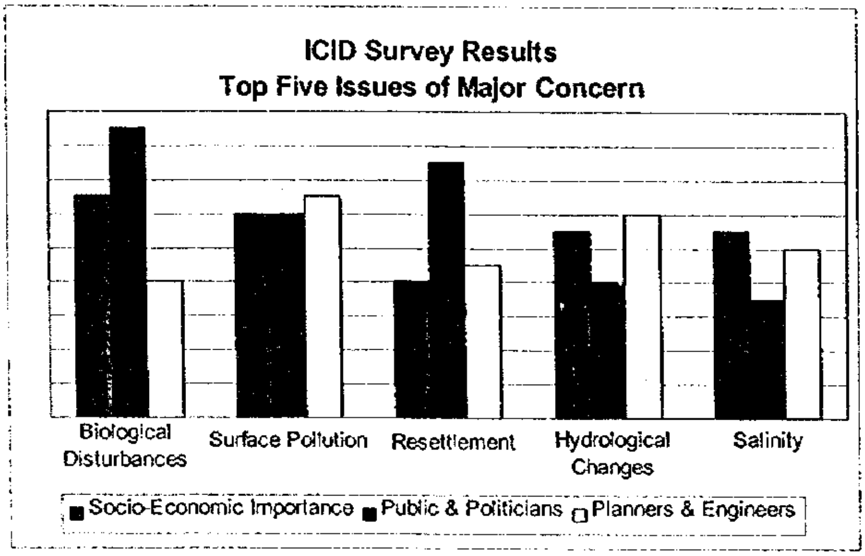
The other major criticisms are largely related to the lack of success of the major projects, specifically major irrigation schemes, in achieving their targets of increased crop production or crop value. Many of these criticisms are of the secondary effects of the projects, such as the salinisation of irrigated land through poor irrigation design or management, the change in cropping patterns from staple food crop production to cash crops with associated loss of food security, and the polluting effects of industries dependent on the power or water resources produced by the reservoir and dam systems.

In the first, and earliest volume, the study briefly refers to the downstream impacts of sediment trapping within the reservoir. These downstream impacts include loss of fertility in the flood plain, and loss of silt deposition in delta areas with associated coastal erosion and damage to estuarine and marine fisheries. The main emphasis is however, on the impact of the sediment trapping in the reservoir itself. The case studies in Volume II included examples from temperate countries as well as from Africa, South America, India and other Asian countries. In virtually all cases that were studied, the actual siltation rates were greatly in excess of the predicted rates, with major implications for the useful life of the reservoir and hence on the economic value of the project. At the same time, the costs of construction and commissioning major dams remains very high and even worse, typically overrun cost estimates by between fifty and one hundred percent. In most cases the costs are met through ***soft loans*** from international agencies, however even these soft loans still need repaying and the result is to impose ever increasing debt burdens on national economies.

The conclusions of Volumes I and II, indicate those areas that were considered *at that time*, as being of greatest priority in terms of requiring mitigating actions. It is interesting to note that the Literature Review (Volume III) coming eight years after the initial overview, contains a number references which discuss wider immediate and secondary downstream impacts. These indicate increased levels of understanding of the inter-relationships between human and natural production systems that have evolved to cope with and ***depend*** on floodplain environments. In addition this concern is an acknowledgement that in many cases the indigenous agricultural production systems can out-perform the imposed irrigation systems both in terms of gross output and gross values of output.

In response to the growing recognition that irrigation and drainage projects are causing concern in many countries, the International Commission on Irrigation and Drainage (ICID) set up a Working Group on Environmental Impacts of Irrigation, Drainage and Flood Control Projects. The long-term objective of the group is to obtain information on environmental effects to provide project planners and managers with improved tools for managing negative impacts. As an initial stage in their assessment the group conducted a questionnaire survey to establish which issues were of major concern to planners and engineers and which were of major concern to the general public and politicians, and whether there were established systems of control within countries to manage adverse effects of development projects. Not surprisingly, technical considerations such as soil salinisation, waterlogging and pollution were given major weighting by engineers and planners, while concerns of social upheaval and impacts on the quality of life are given more weighting by the general public.

However, of major concern to all groups consulted was the impact of projects, particularly drainage and flood control schemes, on the hydrology of the drainage basin. In addition, the impact of projects on the flora and fauna of an area was also of major concern to all groups. These included damage to aquatic systems, loss of fisheries, loss of riparian habitat, and more generally effects on bio-diversity (Brabben 1989).



21.2.2 Environmental Responsibilities

Towards the end of the 1960's, as a result of widespread recognition that uncontrolled development in industrialised countries had resulted in significant environmental degradation, various countries introduced legislation that provided mechanisms for ensuring that environmental considerations were included in the decision making structure. An example of this was the adoption of the National Environmental Policy by the US government in 1969, followed by the National Environmental Policy Act which became law on January 1, 1970.

National policy was soon followed by the creation of mechanisms and legislation to ensure that the policies were adhered to. In 1974 Canada introduced the Environmental Policy and Review Process, ensuring that environmentally sound development was the responsibility of both federal and provincial government. The result of adoption of environmental legislation has been to introduce a degree of accountability into the planning and management processes within national territories; with the extent of accountability largely determined by the corresponding ability to access information.

National policies have now generally been extended to cover bilateral programmes funded by national agencies in other countries[1], in many cases with clear statements that specifically assign the obligation for ensuring that programmes are environmentally sound, with those individuals and agencies responsible for their planning and implementation (e.g. ODA 1992). In addition, where the host country does not have it's own environmental legislation, the policy states that the funding agency, with the host government, must agree on internationally acceptable standards. Following on from this, the funding agency must take account of all international protocols and conventions that have been accepted by the donor country, even if the development programme is in a country that is not signatory to these agreements.

The acceptance of environmental accountability at the national level through those individuals responsible for financing, planning and implementing investment and development programmes, has now been extended through national participation to accountability at the multi-lateral level. Multi-lateral agencies are rarely directly involved in the implementation of development programmes, operating through external agencies, institutions and consultants. The primary role of the multi-lateral agency is therefore in supervision of the financing procedures, with the requirement that mechanisms are used to ensure that the programmes being financed can be demonstrated to be environmentally sound. It is worth noting that, even among the financing institutions, there is recognition that "...free market mechanisms may not bring about society's long term optimum choices..." – *for environmentally sensitive development* (ODA, 1992).

The lead multi-lateral agency, the World Bank, introduced a comprehensive environmental policy in 1984, which has been extended through various specific policy and guideline documents including Wildlands Conservation (Biodiversity) in 1986 and Dams and Reservoirs in 1989. These documents have now effectively been combined into a single document, the Environmental Source Book which covers general policies and procedures as well as sectoral guidelines and even more specifically guidelines for the assessment of energy and industry projects (World Bank 1991). Similar guidelines are being developed by the ECE to ensure that there is a legal basis and sound methodological approach to the advance evaluation of the environmental impact "of planned activities or proposed development schemes and their alternatives which may affect environmental conditions" (ECE, ??).

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[1] In Japan, the Environment Agency created a panel to advise on "Basic Directions for Environmental Considerations in Development Assistance". This panel emphasised the need to base future assistance on Japan's own experience of dealing with environmental problems, and respecting the environmental initiatives of the recipient country (Forrest, 1991).

As a result of these national and international initiatives, and the onus placed on the implementing agencies to ensure that environmental standards are maintained, a number of institutions have expanded their guidelines for ethical practices to include environmental considerations. These include the two principle professional international engineering bodies, WFEO and FIDIC[1], who place the responsibility for advising clients of possible negative environmental impacts, even when they are not included as a specific study component. In one major case, a Canadian consortium has been sued for neglecting environmental clauses while working on designs for the Three Gorges Dam in China.

In summary, it is now generally accepted that both the direct responsibility of the funding agencies and those institutions, companies and individuals planning and implementing investment and development programmes to ensure that decisions are made with full awareness and concern for environmental issues. This is particularly the case where major engineering works, including the construction of reservoirs for hydropower and irrigation, "...are likely to have *significant* adverse impacts that may be sensitive, irreversible and diverse." (World Bank 1993).

However, the existence of environmental legislation and the acceptance of environmental responsibilities at international and national levels, does not ensure that environmental issues are effectively incorporated into the actual management of development programmes. In India, which has had an established environmental legislation since the late 1970's, all plans to build dams are required to have "...environmental clearance from the government "; a recent review indicated that of the 212 dams completed in the last fifteen years, or still under construction, at least 90 percent have failed to comply with the conditions laid down by the environment ministry (Kumar 1995).

21.3 FLOODPLAIN ECOLOGY

As previously discussed floodplains occur throughout temperate and tropical zones, covering typically between one and twenty percent of the land area of any one country[2]. In most cases the ecology of the floodplain is primarily defined by the climate, with the flooding regime superimposing habitat patterns related to increased or excessive water availability. In northern temperate zones floodplains are commonly characterised by water meadows, providing habitats for many species of waterbirds and traditionally used for late season grazing. Studies of bottomland forests in the United States indicated that the overriding factor in controlling regeneration and survival of trees was the length and seasonality of flooding.

Gaudet (1992) defines a floodplain as any region along the course of a river where large seasonal variation in rainfall results in overbank flooding into the surrounding

[1] World Federation of Engineering Organisations 1986 and Federation des Ingenieurs Internationale Conseils 1990.

[2] It has been estimated that seven percent of land area of the United States is subject to significant flood risk. This figure increases to 66% of the land area of Bangladesh.

plains, and distinguishes between wet regions where rainfall within the floodplain saturates the soil causing local flooding which often precedes river flooding, and dry regions where the flood event is driven by rainfall in the upper catchment. In this second case, the floodplain habitat will be dominated by the local effects of the flood regime, over-riding the general climatic patterns of the area. This is particularly true where the river passes through semi-arid and arid environments, and it is only the effects of overbank flow and maintenance of high groundwater levels that create an environment suitable for forest growth.

Three types of floodplain can be identified (Junk 1990):

- Fringing Floodplains – where the floodplain effectively becomes the major channel during high discharge periods;
- Internal Deltas – large floodplains generally developed as a result of geological activity blocking a previous river course;
- Coastal Deltas – typically fan shaped depositionary areas extending into the sea or in-land into large lakes, and now commonly occurring as a result of reservoir construction.

Clearly this characterisation excludes the many transitional and local minor features that define the extent and management potential of floodplains. Floodplains can further be described as amodal, monomodal, bimodal or polymodal, where an amodal floodplain is one in which flooding is an irregular event ocurring at most every few years. Tropical river systems tend to have monomodal or bi-modal flooding cycles, with smaller river systems depending on local rainfall tending towards an amodal pattern.

The critical factor is that the flooding is a regular (seasonal) event and that the floodplain environment has adapted and evolved to depend on this event.

21.3.1 Topographic Features

Within the floodplain, the major variations in habitat relate to regularity and period of flooding. This is largely determined by the main topographic features of the floodplain; depressions with water bodies and permanent or seasonal swamps, and raised areas including levees, sandbars and mudflats. The development of natural levee systems is the result of the immediate deposition of coarse sediments when the river overtops it's banks, as the reduced velocity decreases the transport capacity. The deposition of coarse sediments is then encouraged by vegetation growth, which assists in trapping further sediments. The result of this is that the main river channel can rise above the surrounding alluvial plains, in which the finer sediments are then deposited. These topographic features, with associated water regimes then determine the vegetation patterns.

As alluvial floodplains are generally characterised by highly mobile river channels, with major shifts resulting from the less frequent large flood events, the floodplain itself is a mosaic of old channels and cut-offs, of coarse and fine lenses of sediments, supporting a complex pattern of vegetation. Away from the river and the immediate effects of groundwater, the topographic effects become even more critical, with micro-topographic features determining flooding patterns and flooding depths.

The typical pattern then ranges from open water bodies in the lowest, wettest areas, through permanent swamp to grassland and finally, in the drier areas forest and bushland.

Lakes	Large water bodies, relatively unchanged over a number of years
Lagoons	Water bodies connected to the main channel throughout the year
Pools	Small water bodies, which become isolated and dry out in some seasons
Swamps	Areas where the soil remains saturated throughout much of the year, but without significant areas of permanent free standing water.
Floodplain Grassland	Seasonally flooded grassland, to the extent that soil conditions preclude tree growth
Floodplain Woodland	Occurs at the higher margins of the floodplain, if the general climatic conditions can support woodland
Fringing Forest	Coarse, well drained levee soils supporting forest growth on high water tables.

21.3.2 Floodplain Productivity

Following on from the general climatic factors and water availability, the determining factor in gross productivity is the nutrient input to the system. This input is directly attributable to the nutrient load carried by the river, both as sediments in suspension, and as a dissolved chemical load. There is considerable dispute over the exact extent to which productivity is determined by the recycling of nutrients within the floodplain system, but the final limiting factor must be the external nutrient input. Studies carried out in the Sudd indicated that it does not act as a long term nutrient trap, as most of the inputs will be taken up in the organic plant fraction, which will be recycled within the wetlands or flushed back into the river system. However the modifying effect of the floodplain on the seasonal water quality is clear, the provision of flood water with high nutrient load, leads to rapid growth conditions that themselves absorb high quantities of nutrients. Similar conclusions are reported by Gaudet for his studies in Kenya and Uganda.

In swamp areas, this nutrient flush is accompanied by an explosive growth of phytoplankton, followed by a zooplankton bloom and later by a growth of macrophytes. In shallow flooded areas, there is an immediate response from grasses and emergents.

Gaudet describes African floodplains as being dominated by herbaceous monocotyledons, the most typical being tropical wetland grasses[1] with sedges in deeper flooded areas, and estimated net grassland production as being between 10 and 20 tons of dry matter per hectare per year[2]. He notes that these levels of production can only be sustained in most commercial crops with the use of heavy applications of artificial fertilisers.

The high rate of primary production of floodplains is clearly the critical factor in the overall productivity of these areas, "...especially in Africa where they support large numbers of domestic and wild animals." (Gaudet, 1992). In addition, the quality of the grasses is high with a high crude protein content and they remain highly palatable, even when dry.

21.3.2.1 Vegetation Communities

Apart from the very clear delineation of levee structures, the rest of the floodplain environment is effectively a continuum from low and wet to high and dry areas. The vegetation patterns therefore also reflect this continuum, with plant species appearing across a range of environments, adapted to specific flooding and soil conditions. Given the complexity of floodplain environments and the effects of micro-topography on the water regime, these vegetation associations are often difficult to describe, other than in very general terms.

The most common successional sequence in Africa is from aquatic emergent to typical savannah species (*Vossia* – *Oryza* – *Hyparrhenia*). This sequence has been noted in Sudan (the Sudd), Zambia (Kafue Flats and Chambeshi Plains) and throughout West Africa. The relative proportion of each component varies, for example with *Vossia* predominating in fringing wetlands in Zaire and *Oryza* in the Kafue Flats in Zambia. Within this general dominant pattern of successional grasses there are also significant areas where there are major differences in the associated non-dominant species, where the micro-topographic and soil conditions have created specific niches.

The general conclusion is that the maximum depth of flooding is the limiting factor in plant communities, with the length of the flood a secondary factor.

Although the grasslands form the major system, in terms of extent, in all floodplains, it is often the forests that are the dominant feature. This is particularly so in arid and semi-arid areas where the climatic limits restrict the surrounding area to savannah. Riverine and floodplain forests provide unique habitats that are then very different from the surrounding areas, and are not part of a vegetation continuum in the same

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1 The most common African grasses include *Sporobolus, Echinochloa, Oryza, Vossia, Phragmites, Paspalum, Miscanthidium* and *Panicum*; the most common sedges include *Papyrus* and *Typha* (Bulrush).

2 *Papyrus* has been recorded as producing between 50 and 140 tons (dry matter) per year, even in conditions of low nutrient load. *Typha* production averages 16 tons per hectare in the Lake Chilwa swamps in Malawi. In the Amazon, *Paspalum repens* has been recorded as producing between 12 and 16 tons per year.

way as the grass associations. These in turn can support different wildlife species and provide resources for local use that are not available elsewhere.

Table 21.1 Floodplain Grass Associations (Zambia)

Dominant Environmental Condition	Main Grass Associations
Permanent Swamp	*Vossia cuspidata* *Echinocloa scabra* + *Cyperus papyrus* *Leersia hexandria* + *Echinocloa pyramidalis*
Deep Flooded Grassland Long Flood	*Oryza perennis* + *Echinocloa pyramidalis*
Deep Flooded Grassland Short Flood	*Leersia hexandra* + *Acroceras macrum* + *Paspalum commersonii*
Shallow Flooded Grassland Long Flood	*Setaria avettae* + *Vetiveria nigritania*
Shallow Flooded Grassland Short Flood	*Cynodon dactylon* *Setaria sphacelata* + *Themeda triandra*
Floodplain Margins	*Hyparrhenia rufa* + *Setaria sphacelata* + *Panicum coloratum*

Source: Gaudet 1992.

The dependence of riverine forests on flood events is complex. The primary requirement is for availability of groundwater throughout the year, forests are therefore restricted to areas near the main river channels, or in areas where local soil conditions have resulted in a perched water table. However, the establishment of forests and the creation of new environments in areas where the river channels are mobile, depends on flood events that may be irregular. The natural regeneration pattern of many floodplain forests and woodlands reflects this dependence on irregular events, and can be seen in the distinct and disjunctive age structures (Adams, 1989). Even aged stands have been recorded in Tanzania, Kenya and Sudan.

The significance of riverine forests has been described in detail for two floodplains in Kenya, the Turkwel and Tana Rivers. The Turkwel river woodlands are dominated by *Acacia tortilis* with extensive stands of *Hyphaenia coriacea*. Although the same species of Acacia is found away from the river, it is only in the immediate area of high groundwater that the tree attains full size; the outer edge of the riverine forest or woodland is determined by the depth of the watertable and the ability of the root system to reach it. These woodlands support a wide range of domestic and wild animals, and are particularly important for pastoralist communities. The presence of animals also enhances the regeneration potential of these woodlands, as the germination rates for digested seeds are significantly higher than for those that have not passed through the system. In the case of the Turkwel river, where the major influence is from domestic stock, Adams (1989) considers that the present extent of the woodlands may be considered to be in part anthropogenic, as the regeneration of seed will depend on the grazing management practised in the woodlands.

A similar mechanism has been proposed between hippopotamus and *Acacia albida* in the Luanga and Zambezi valleys in Zambia, where Acacia colonises fresh silt deposits within the floodplain.

Hughes (1990) describes the Tana river forests, where the evergreen forests grow on the highest part of the floodplain nearest the river. The forests are generally restricted to a belt of about one kilometre within the floodplain of typically six kilometres. These forests are of great conservation interest as they provide the only habitat for two endemic primates. Hughes makes a distinction between active and inactive levee forests and a clear distinction between the evergreen levee forests and the Acacia forests which occur at some distance from the levee. The conclusions of the study were that the suitability of the environment is defined by the frequency and period of flooding. The greatest Biodiversity is found in these levee forests.

All evergreen forests were above bankfull discharge, and were flooded at most only every other year, with much of the forest in higher areas which would expect a flood far less frequently, with a maximum flood period of less than one month and an average flood period of less than 10 days. Effectively the regular small flood events maintain the high groundwater necessary to support forest growth in an otherwise semi-arid environment, and the less frequent major flood events create new environments in which regeneration can take place, as well as destroying forest environments.

The forests and indeed the whole floodplain must therefore be considered as both flood dependent and flood tolerant habitats.

21.3.3 Fisheries

Annual flooding in many cases also triggers the breeding of riverine fish, as the flood waters release a rich source of food and the floodplain vegetation provides protection for spawning fish, eggs and fry (Acreman 1994). Many species of edible fish breed exclusively in the inundated floodplains, and techniques have been developed to harvest this important source of protein.

The benefits of floods extend to the inshore fisheries, again through the direct provision of nutrients and through the creation of brackish habitats in which many economically important marine species spend part of their lifecycle.

It has been shown that there is a rough correlation between the number of fish species found in any river system and the area of the basin[1] (Junk 1990). Clearly not all fish species will be represented at any one point within the river system, but generally the

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1 In the tropics, Jung suggests that a formula N (number of species)=0.36 A(basin area)$^{0.47}$; A river the size of the Tana River would therefore be expected to have around 80 fish species.

larger the river, the more species will comprise communities that are susceptible to harvesting throughout the system.

In more stable environments species tend to be described according to their spatial and trophic niches, however in floodplains this desciptive system breaks down as the adaptation to habitat changes has resulted in far greater community mobility. Effectively two groups of species have developed: one group of species moves relatively short distances within the floodplain, capable of surviving in the deoxygenated water associated with heavily vegetated floodplains through a number of adaptations including the ability to breath air or air enriched surface water, and with breeding patterns that put their fry in better oxygenated areas; the second adaptation is avoidance of adverse conditions through migration into better oxygenated upstream areas during rising flood periods.

As a result, a clear seasonality has developed in response to the regular flooding cycles.

- Breeding – tends to occur at the beginning of the floods, with migratory species breeding upstream and releasing eggs and larvae to be washed into the floodplain system, and floodplain species breeding in channels and along the advancing fringe of the floods. In both cases the young are able to make full use of the massive increase in food availability associated with the early floods, and in areas providing shelter from predators.
- Feeding and Growth– as a result of the ready availability of food during the flood period, and with low initial fish densities, growth is maximal at the time of the flood. Many floodplain species can put on 80% of their annual growth in the short period between the start of the flood and the flood peak. As food becomes scarce during the dry season, and fish return to the main channels, many species go into semi-hibernation and fast for the full dry season, relying on stored fat, not only for maintenance of metabolic functions, but also enough to carry through the start of the breeding cycle before food is again readily available with the floods.

The predators have also developed similar, but delayed, breeding – feeding cycles, with some predators concentrating their feeding during the period when the young prey species are returning to the main channels and are therefore most concentrated and vulnerable.

A number of models have been developed to describe fisheries population growths within the floodplain cycle, to try to define maximum sustainable yields (Jung 1990), however none have as yet been adequately tested.

Maintenance of floodplain fisheries requires the management of the original or slightly modified natural ecosystem. This includes the management of water quality which in turn implies the control of agricultural and industrial activities in the upper catchment.

In addition, given the clear adaptation to flooding cycles "...*as some measure of flow control is introduced, it may be necessary to impose controls on the timing and quantity of water in the system, especially that needed to ensure migration and breeding of fish in small streams.*"

21.4 FLOOD RELEASE

Flood release has been considered as a management tool for downstream systems by planners at initial planning stages before construction work has started on new reservoirs, but it would appear that the by the time the final designs are completed the proposal to release floods has in almost all cases, been lost.

When the downstream effects become so damaging that planners and managers can no longer ignore them as being minor inconveniences or dismiss them as being economically insignificant, then a decision may be made to release floods, through a structure that has not been designed for this and may need expensive modifications.

Proposals for the rehabilitation of floodplains, damaged as a result of upstream water developments, through the release of managed floods are now quite common. However, the actuality of flood release is rather rarer.

21.4.1 Planned for Flood Release

The need for integrated planning within a complete watershed has been generally accepted and the River Basin Authority seems to offer the appropriate institution for managing the integrated development of the environment. The earliest and most quoted model for the management of water resources within a single catchment is the Tennessee Valley Authority (TVA). This is a federal corporation, created by the Congress of the United States in 1933 to operate Wilson Dam and to develop the Tennessee River and its tributaries in the interest of navigation, flood control, and the production and distribution of electricity (Microsoft 1995). Related TVA activities, based on the original TVA Act and subsequent enactments, include reforestation and industrial and community development.

Nigeria was one of the earliest developing countries to adopt the model, with the establishment of two River Basin Development Authorities (RBDA's) in 1974, covering the Chad and Sokoto-Rima basins. However, the concept of integrated development preceded even this and there were proposals for the establishment of the Sokoto Valley Flood and Irrigation Authority presented in 1969 that acknowledged the integrated nature of the basin and specifically that the Sokoto floodplain had been a major agricultural production area for a very long time with the development of a farming system that relied on the extensive cultivation of rice during the wet season and vegetable crops in the dry season (Adams 1985).

With the assistance of FAO, plans were drawn up for the expansion of irrigated farming through the phased development of a reservoir and associated irrigation development at Talata Malafra on the Sokoto river. Expansion of irrigation was expected to be a slow process, as Nigeria had little experience of large irrigated schemes. The 1969 proposal stressed the need to maintain "...the existing patterns of life" in the lower floodplains, and the reservoir was to have a storage capacity twice that required for irrigation. The proposal included the maintenance of downstream flows during and after construction and that subsequent projects be integrated with the overall land use patterns within the scheme. The project was approved and the detailed design works were put out to tender in 1971.

During the design process the scale of the project was significantly expanded and became known as the Bakalori Dam Project. During this detailed design process the proposed irrigated area was increased by 240%, and at the same time the storage capacity of the reservoir reduced. It is worth mentioning that no environmental impact study was ever carried out.

This was how the reservoir was eventually constructed and the effect was predictably to reduce the overall downstream agricultural production. Rice production decreased and was replaced with lower yielding dryland crops, sorghum and millet. Dry season vegetable production also declined. Fishing was also seriously effected and yield decreases are quoted of between 50 and 70 percent.

21.4.2 Built for Flood Release

Even if the planned flood remains a component throughout the period of design and construction, this is still no guarantee that it will be effective or remain a management objective once construction of the dams has been completed.

A clear example of this is the development of the Kafue Flats, through which flows one of the major tributaries of the Zambezi. This major wetland area in Zambia, before development, provided dry season grazing for between 10 and 20 percent of the national herd (Acreman 1994), as well as providing the largest artisanal fisheries. Acreman reports the Kafue Flats as being considered the single most valuable agricultural entity in Zambia.

The development of the hydropower potential of the Kafue basin followed the construction of the Kariba dam, and was based on the construction of two dams. The first dam would be built at Kafue Gorge, but as the storage capacity would be limited by the upstream terrain, a second dam was proposed for Itezhitezhi both for hydropower development and as a regulatory reservoir feeding the Kafue Gorge dam.

At the very start of the planning phase, it was realised that the Kafue situation would be more complex than the previous development of Kariba, particularly as there were existing water rights to urban settlements, including Lusaka and to agricultural developments. Between 1962 and 1966, a joint study was carried out by UNDP/FAO and the Government of Zambia on the optimum use of land and water resources, and in 1969 and 1970 a further study specifically looked at the biological resources. The conclusions of the Kafue Basin Research Committee are quoted as "...the biological productivity of such an area as the Kafue Flats may in the long run prove to be vastly more important to mankind than it's short term value as a modified water storage for the generation of hydropower.". As a result it was agreed that the design for

Itezhitezhi would incorporate enough excess storage to provide an annual artificial flood (a "freshet" of 300 m^3/sec) over a one month period in March. This was built into the design and implemented, and resulted in an overall cost increase of around 15%. The Kafue Gorge Dam was completed in 1972 and the Itezhitezhi Dam was completed in 1977.

Initially it was planned to maintain as much of the annual flooding cycle as practical during the period of construction of the upstream regulatory dam (Gaudet, 1992). However, during 1973, one year after the completion of the Kafue Gorge dam, the area experienced the driest season on record; the floodplain drained apart from one remnant lagoon structure and most the area was affected by burning. As a result of this, in subsequent years, the management was altered to increase the storage and the water level was raised to 1.2 metres above "normal" floods, leading to loss of much of the seasonal grassland. On completion of the Itezhitezhi dam, the combined management was then aimed at using the upstream reservoir as a regulatory mechanism and despite the release of artificial floods the wet season flooded area was reduced, but the dry season area then remained permanently flooded. Finally, as a result of geological activity, the Itezhitezhi dam developed structural faults and had to be drained, and all possibility for upstream management was halted.

The management problems have not been helped by the fact that the design was based on poor hydrological data; it is now clear that the majority of flow data on which the design was based came from what is now recognised as a high flow period, and the existing water user allocations for the formal sector exceed average flows by 14%, leaving no surplus for the natural management of the floodplain system. IUCN reports suggest that "...the operators of the dam *observe their own priorities* when they are incompatible with flow regimes that will benefit riverine habitats and populations...".

21.4.3 Modified for Flood Release

Even when not recognised or acknowledged before implementation, in many cases the damage to downstream social, economic and ecological systems could not be ignored.

The Pongolopoort Dam, in north-east Natal in South Africa, was constructed in the 1960s to provide storage for a proposed irrigated development of 4,000 commercial sugar farms aimed at an identified *poor white farming community* (Poultney 1992). The floodplain was already supporting a large local population dependent on flood recession farming, fishing livestock herding. These original inhabitants were effectively squatters living illegally on government. The immediate effect of the dam was to change the flooding pattern of the whole downstream system leading to major loss of crop production. In the event, the irrigated farming development never took place, and the dam was then managed to release floods. However, the timing and quantity of flood release was managed by the Department of Water Affairs, without reference to the requirements of downstream users, and as a result crop damage continued to occur as floods lasted too long or washed away young plants. In 1984 the area was hit by a major cyclone, and the reservoir level rose to 87% of it's capacity in five days and the authorities were concerned that there could be a major disaster. In the event, there was no major disaster, but the conflicting messages that had been passed by different agencies to the downstream population were so confused that it became apparent to Department of Water that there system of communication was inadequate.

As a result in 1987, it was agreed that water committees would be established composed of representatives of the different downstream user groups, fishermen, arable farmers, livestock keepers and specifically including women and health workers. These committees then meet with the Department of Water dam authorities and negotiate a mutually acceptable flood release based on an agreed release date and period of flooding. The management system now appears to be functioning to the benefit of the user communities[1].

A rather less successful example of the deliberate release of floods occurs on the Senegal River. The planning for the development of the Manantali and Diama Dams on the Senegal river started at a similar time to the Pongolopoort Dam, in the early 1960's. The process was much more complex, as the basin of the Senegal River includes three countries, Mali, Mauritania and Senegal. These countries established a joint planning body the *Organisation pour la Mise en Valeur du Fleuve Senegal* (OMVS) to supervise development in the basin. The purpose of the Diama Dam at the mouth of the river, was to limit salt water intrusion to allow the river water to be used for irrigation and to regulate water levels to improve the potential for river transport The Manantali Dam was built to generate hydropower and to regulate flows in the river and allow for the development of irrigation systems within the floodplain. Originally the floodplain supported up to 250,000 ha of flood recession farming, as well as livestock, fisheries and forests and other wildlife habitats (Acreman 1994).

Although not included in the original design concepts, by the time construction was started in 1986, it was recognised that the development of the downstream irrigation would proceed more slowly than the dam construction and it was agreed by OMVS that they would release controlled floods for a transitional period. The first floods were released in 1988, based on an assumed potential to maintain 50,000 hectares of flood recession farming. So far the dams have not been fully commissioned, but OMVS are claiming that the release of floods will reduce the potential for hydropower generation by 25%, and that this is incompatible with the national economic interests.

Meanwhile, the development of irrigation has not taken place to any significant degree and the volume of floods released by OMVS is insufficient to replicate natural flooding patterns, in addition, the potential of the proposed irrigated cash crop system has largely collapsed, as commodity prices have fallen on the world market. Many of

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1 It is worth noting that the involvement of community groups in any government decision making process was very rare, and the establishment of these committees was a very radical step to which there was considerable opposition. The water committees have to some extent now taken over a wider community representation role, to the considerable concern of some of the traditional authorities who are losing their power base in the decision making process. As a result there has been some interference in the functioning of the committees.

these problems were foreseen in a report prepared in 1977 on the overall package of OMVS proposals (LeMarquand 1990).

21.4.4 Proposed for Flood Release

Despite the fact that flood release has never been included in the original designs for reservoir management, or where it has it has not been successful, it is clear that it could be a potentially beneficial management tool.

As a result there are now a number of proposals to adapt the management of existing reservoirs for the permanent release of floods to the downstream systems and proposals for new reservoirs to be designed with the capacity to manage flood release.

In Nigeria there has been a formal agreement to include flood as a management tool in the Komodugu-Yobe basin, which includes the major Hadejia-Nguru wetlands area and has a number of existing dam developments. The agreement was reached at a meeting held in Kuru that included representatives from the RBDA's, state water authorities, government departments and research institutions. At this meeting it was demonstrated that, among other aspects the best use of the water resources in the basin is through the support of the diversity of the production systems, that include large scale irrigation systems, small scale irrigation and the traditional production systems that depend on flooding (Thompson & Hollis 1995). To this end the agreement states that "...flooding in the wetlands made possible by artificial releases from dams in the wet season should be maintained..." and that this applies to the management of existing facilities and to proposed future developments including the planned Kafin Zaki dam (Acreman 1994).

The conclusions of this meeting on the returns to major irrigation investments, one of the commonest justifications for reservoir developments, are confirmed by the World Bank Nigeria: Impact Evaluation Report (World Bank 1995) which assessed the success of one component of the Kano and Sokoto Agricultural Development Projects. The one component that showed significant benefits was the promotion of small-scale irrigation building on traditional flood farming systems carried out in the seasonally flooded river valleys (*Fadama*). This was in direct contrast to the experiences of other funded development projects in West Africa based on large scale irrigation in similar valley bottom situations[1].

Similar proposals have been made for the rehabilitation of the Logone floodplain in Cameroon, through the deliberate management of water releases. The floodplain here has been affected by the construction of the Maga dam and associated structures designed to protect newly developed irrigated rice. An agreement was signed in 1991 between the Government of Cameroon and IUCN for a study on restoring the natural flooding patterns (financed by the Netherlands). The floodplain covers an area of 6,000 km^2 and before the construction of the dam, provided the local population with

[1] It is worth noting that the same World Bank report states that "...large dams constructed in Northern Nigeria have had a demonstrable impact on downstream hydrology with consequent impacts on fish and wildlife...".

their primary economic activity, the floodplain fisheries as well as a huge pastoralist grazing reserve during the dry season.

The possibilities being considered now include the management of the hydrological regime above the Maga Dam, to improve gross water availability, as well as management of releases from the reservoir and the restoration of flood channels and construction of new artificial flood channels (Wesseling *et al.* 1995). The conclusions of the study were that the initial (pilot) intervention would be the re-opening of the original flood channel and increasing the release from the existing spillways, with improved overall management of water in the reservoir to provide this additional water output. This will have been carried out and monitored for the first time during the 1994/95 season.

Proposals have also been made in Kenya for the release of floods as a management strategy for the floodplain of the Turkwell River, downstream of the Turkwell Gorge Dam (Adams 1989). However, this does not yet appear to have been followed up, and the reservoir, designed with only seven years of flow data at the Gorge itself, has not yet filled nor come fully on line as a hydropower source[1].

Another example of a proposal for the managed release of water for the downstream environment is now under discussion in India, although these are primarily directed at minimum flows rather than controlled floods. The Sardar Sarovar projects on the Narmada River in western India have long been under discussion in terms of their management from the point of view of the social and economic impacts of dam construction. The projects are aimed at providing drinking water to 30 million people, as well as providing hydropower and water for irrigation.

The World Bank initially funded much of the development through a ten year Dam and Power Project and an associated three year Water Deliver and Drainage Project. In 1992 the Bank commissioned an independent review in 1992 in which it became clear that resettlement and environmental aspects of the programme were not being managed in accordance with Bank policy. As a result the Bank made it a condition of further support that the borrower achieved performance standards set for resettlement and environmental protection. In the event, these were not forthcoming and at the request of the Indian Government, the bank cancelled the loan in 1993. The government is now committed to completing the projects with funding from other sources (World Bank 1995).

In March 1995, the Bank's South Asia Region issued Project Completion Reports on the Narmada Project. These documents stressed "...the need to safeguard downstream environments by maintaining adequate water releases from the dam from the start...", rather than risk incurring environmental damage that would then require greater

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[1] Adams states that it appears that the design of the dam may allow for some flexibility in the management of releases which could be used to minimise negative downstream impacts. Conversely he warns that, unless there is some managed flood release there will be a serious negative impact on the floodplain woodland and on the pastoral economy of the Turkana.

releases of water at a loss to the upstream developments[1]. The *costs* of the project are expected to include changed river sedimentation rates and reduced yield of artisanal fisheries in the Gulf of Khambat.

Even in projects that are looking at the environment from the opposite perspective of ***flood mitigation***, similar conclusions have been reached. Following the disastrous floods in 1987 and 1988 in Bangladesh, UNDP funded a Flood Policy Study which proposed the preparation of a Flood Master Plan based on the construction of embankments and flood compartments that would absorb controlled overbank flow along the major rivers. The proposals were discussed at a meeting held in Paris in 1989 which was followed by the World Bank preparing an Action Plan for Flood Control, which included both structural interventions and institutional interventions including the improvement of flood warning and flood preparation systems (Brammer 1990).

The structural interventions include the protection of major cities and other infrastructure through traditional river training techniques, while in the rural areas the proposal excludes the possibility of total flood control. Instead a system of regulators and sluices will allow for controlled flooding at ***normal*** levels, to which the traditional farming systems have adapted. It is expected that this will provide additional environmental and social benefits including the maintenance of fish production, increased groundwater recharge and management of soil fertility and natural pest and disease control. Flood damage can be minimised by developing a system adapted to and benefiting from regular floods, which will also have the critical function of excluding inappropriate developments from inherently threatened floodplain areas[2].

In conclusion, it is clear that recent design proposals for flood management acknowledge the need for flood events that reflect natural cycles, if downstream environmental and socio-economic systems are to be maintained, and in addition that systems capable of delivering regular flood release are also an essential component of flood protection.

21.5 SEDIMENT RELEASE

In the majority of river systems there is a direct linkage between sediment transport and flooding periods. Clearly the transport capacity increases with stream velocity during flood periods, but in addition it is the upstream rainfall that generates the flooding, which both causes erosion and through surface flow and transports the eroded materials in the river system.

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[1] There are in addition some outstanding questions on the hydrological data and analyses. Although the PCR accepts that the river flows are adequately understood, in view of the need to maintain flows to protect the downstream environment and uncertainties over future upstream developments, there will not be adequate water to irrigate all the proposed upstream command area.

[2] It should be noted that, despite the initial conclusions of the IBRD studies, there is still a considerable engineering based lobby that are not happy with concepts of controlled flood release, and still believe that a total control system could be implemented successfully, although at significantly greater costs.

A study of the transport mechanisms which influence the structure of river systems concluded that the dominant floods were not the major infrequent events, but the regular seasonal floods. The relative importance of the flows can be compared by combining the frequency of each event with the amount of sediment transported (Wolman 1960). Very simply, at above a minimum critical level all flows will transport sediment through the river system, and the cumulative sediment transport capacity of the regular low flows will exceed the transport capacity of the infrequent high flows (e.g. the infrequent damaging floods). The study looked at the transport capacity of two very different river systems in the United States, one in a humid region and one in a semi-arid region, and concluded that the "catastrophic floods" occurring once every fifty years or less, are only responsible for ten percent of the sediment transport; "***Although the extremely large floods carry greater quantities of sediment, they occur so rarely that from the standpoint of transport their over-all effectiveness is less than that of the smaller and more frequent floods.***".

The additional point that needs to be incorporated is the seasonality of the transport mechanism that releases sediment into the river system. This appears to be most complex in temperate river systems where the highest flows are often associated with spring snow melt in the upper catchment, but the greatest sediment input occurs during the lower flow periods associated with the summer rains. Again the study looked at a series of river basins within the United States and concluded that "***Events which recur more than once per year account for 78–95 percent of the total suspended load.***". The study did indicate that the greater the variability of the runoff, the larger percentage of the total load that is likely to be carried by infrequent flows, and given the statistical variability of rainfall, the more significant this becomes when associated with small drainage basins.

The study also looked at the balance between the dissolved and suspended sediment load, and the seasonality of transport of dissolved load. Although the process of solution may be aided by fast-flowing streams, the major factors controlling dissolved loads are the presence of soluble permeable rocks and high rainfall in the upper catchment. While suspended sediment load will generally increase both in terms of concentration and volume with increasing flow, dissolved concentrations will often decrease. This apparent paradox is due to the fact that the major input of dissolved load is contributed from ground-water flow, and that this groundwater input is diluted by high overland flow during flood periods. It follows that the higher the percentage of total load that is carried in solution, the more the relative importance of the regular low flows. In general, the percentage of dissolved load increases with precipitation and vegetation cover, as overland sediment transport is reduced through maintenance of groundcover.

It therefore appears that for both suspended and disolved sediment load, the major cumulative transport mechanisms are the regular low flood or flow events.

The immediate effect of dam construction is to trap much of the suspended sediment load within the reservoir body. The impact of trapping sediment on the downstream system is twofold: the erosivity of the flow is increased which can lead to bed degradation and channel movements; and the loss of sediment can change nutrient levels and productivity of downstream systems. Changes in landuse patterns in the upper catchment can significantly change sediment load, with the result that planned reservoir life can be significantly reduced[1].

The implication is that storage reservoirs will always be subject to loss of volume as a result of silting, unless deliberate mechanisms are included to divert sediment laden flow through the system. In the majority of cases the engineers response is not to avoid sediment trapping, but to *accept* a limited reservoir life and if necessary to increase storage volume.

The second approach, with an initial design to accommodate sediment storage, was taken for the Aswan Dam. The sediment load at the dam site has been calculated as about 134 million tons per year, and the dead storage capacity of the reservoir has been designed to be 31 billion tons[2]. Silt is accumulating in seasonal layers of about one metre depth in the southern, upstream half of the reservoir (Pearce 1994). At this rate it should still be over one hundred years before siltation begins to affect the performance of the reservoir.

The alternative approach of sediment release is being proposed for the Three Gorges Reservoir on the Yangtze River in China. This river is extremely seasonal, reaching average flows of over 30,000 m^3/sec during July and carrying an annual estimated suspended sediment load of 521 million tonnes, with an additional 757,000 tonnes of gravel bedload (Jisheng 1994). Typically the majority of sediment transport is during the flood season from June to September, during which period 80% of the suspended sediment load is carried by 60% of the annual runoff.

The proposed site, with the reservoir backing-up through a gorge system, means that the potential storage volume is very low compared to the annual runoff.

Given the low dead storage and the high sediment load, combined with the dual needs of maintaining a navigable river and the production of hydropower, the reservoir will have to be operated more on the lines of a run of the river system than a storage reservoir. The operating procedure will therefore be to drop the water level to a flood control level in advance of the flood period and to release the early turbid flood waters, only storing the clear late decreasing-flood water to the normal pool level to provide for increased dry season release.

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1 The situation in Kenya, and in particular on the Tana River, reflects the effects of changed land use on sediment load. The sediment load, above the present reservoir site at Kindaruma, was originally estimated to be 300,000 tonnes per year. More recent estimates based on measurements and linked to changed land use, indicate that the levels are in the order of 7,000,000 tonnes per year (Ongwenyi 1985).

2 The gross annual sediment concentration levels in the Nile at Aswan and in the Tana River are very similar, although the Tana has two potential flood seasons for the single season Nile flow. Total annual flow in the Tana is one thirteenth of the total Nile flow, and carries around a thirteenth of the total sediment load.

Table 21.1 Characteristics of Three Gorges and Aswan Reservoirs

	Three Gorges Reservoir	Aswan Dam
Shape	Narrow river type	Wide Basin
Live Storage compared to annual Runoff	5%	150%
Dead Storage compared to annual Sediment Load	32 times	250 times
Reservoir Operation	Early turbid flood released, only late clear flood stored to increase dry season discharge.	Flood water retained to increase dry season discharge.

However, even with this flood release, it is expected that sediment outflow will only amount to 30% of sediment inflow in the first ten years, gradually increasing to 80% after 70 years. In addition, as much of the gravel bedload will be trapped, changing the composition of the sediment outflow, downstream bed degradation is expected to occur over a distance of 870 kilometres. This is expected to occur despite the provision of 23 deep outlets and 22 surface bays to improve sediment flushing from the main reservoir, with additional sediment structures provided in the powerplant facilities (Jiazhu 1994). The effect of the silt scouring gates is to remove only those deposits within a few hundred metres of the dam, protecting the generator intakes (Fearnside 1988).

In practice, it would appear that there has not been a dam system effectively operated to manage ***release*** of sediments to maintain the stability of downstream environments. Even in the proposed schemes where the release is part of the management strategy, this is largely carried out in order to protect turbines and enhance reservoir lifetime, and not to mitigate against deleterious impacts on downstream systems. Even in such cases, the immediate decrease in sediment transport that still occurs despite sediment release mechanisms will have significant downstream effects.

21.6 DOWNSTREAM ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACTS

The need for the mitigation of the immediate effects of the reservoir has long been recognised, most obviously in the associated resettlement programmes for the displaced populations. In some cases this has been seen as an opportunity for social engineering, through the creation of modern settlements[1].

The downstream impacts have also been widely recorded but the mitigation of downstream effects has rarely been addressed. The majority of direct effects are felt within the floodplain areas, with secondary effects extending into the hinterland. It is true however, that in many cases it is also in the floodplains that secondary development takes place, in particular the development of irrigation schemes deriving water from the upstream reservoir. However, in many instances these developments fail to compensate for the loss of production and dissruption to social and economic systems.

Reservoir development will always have a degree of negative impacts that may not be able to be mitigated against; and the benefits of the project may not go to those people who have suffered as a result of the development. In overall terms the development may have been to the national good, but at a local cost.

From this literature review it appears that flood and sediment release has not yet been a deliberate or active component of reservoir management, the following section therefore deals only with the downstream impacts of decreased flood and sediment release.

One clear problem with the assessment of impacts, is that in most cases there has been little or no systematic collection of baseline data in the downstream areas *prior* to dam construction. To some extent the pre-dam situation has to be assessed through a back projection of the existing changed situation, supported by peripheral data collected for other purposes such as a livestock census or health survey.

In general, the only data that is consistently available for the ***before and after*** situation is the measurement of river flow[2]. If these flow data are combined with a

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[1] The resettlement that took place as a result of the flooding of the Volta reservoir in Ghana, was seen as an opportunity for the modernisation of rural life, bringing in mechanised farming and proper housing (Schmidt-Kalllert 1990). In the event, farm sizes which were planned to be 4.8 ha were laid out at 1.2 ha per family and the programme never developed. The original settled population of 77,000 people at one stage dropped to 25,000 as families migrated in search of land; the water supply systems have largely collapsed; in 1980 as much as 90% of adjacent populations were infected with river blindness, similar figures for bilharzia were found in 1970, pre dam levels were around 2%.

[2] Even flow data can be misleading, and there are many cases where dam design has been based on a flow series that has been shown to be unrepresentative of the general river flow conditions, or of the trend in river flow conditions. Examples of this include the Nile, where the Aswan Dam was designed on a data series that indicated an average flow of 2,700m^3/sec, on which the agreement between Egypt and Sudan was based; since then the average flow during the 1980's dropped by 10%, and was particularly low between 1984 and 1987 at 60% of the previously estimated flow.

dynamic hydraulic model of the floodplain, then the pre-dam flooding situation can be deduced. In cases where a series of dams have been constructed, each dam can then be successively removed from the model to give an indication of the "natural" flooding conditions. However for a detailed assessment, given the significance of micro-toopography in flood extent and duration, it is necessary to have an accurate topographic model of the floodplain based on sub-metre contours – information that is rarely available.

One example where this type of modelling has been done is in the Murray-Darling basin in Australia (Maheshwari, 1995). The flow pattern of the Murray River has been significantly changed over the last century through successive phases of development of dams, weirs and levees, as well as changes to the operational procedures of the dams themselves. The model indicates that both average and annual monthly flows are considerably lower than the natural, unregulated flow conditions. However the most significant changes are in the seasonal pattern of flows; the magnitude of the average annual floods (high frequency, low volume floods) has been reduced by over 50%, but the major flood events (one in 20 year floods) have not been significantly reduced[1].

21.6.1 Environmental Impacts

The major impacts all relate to the changed floodplain environment, in some cases extending to the delta and estuarine systems, through loss of flooding and loss of flood-borne sediment. The key factor is the extent and duration of surface flooding, dependent on overbank discharge, which in turn increases aquifer discharge.

The following habitats and production systems may be expected to be changed by the loss of floods:

- Openwater – decreased extent and period; leading to reduced gross fish production and changed species composition;
- Grassland – decreased extent of floodplain grassland, replaced by rainfed grasslands of lower productivity, changed species composition and bush encroachment; decreased carrying capacity for wildlife, both grazers and predators, and decreased carrying capacity for domestic stock;
- Riverine and floodplain forest – decreased extent of forest areas; replacement with less productive dryland forest or bushland; loss of endemic species.

The effects of the development of irrigation, that included both flood diversion structures and the construction of a storage reservoir on the Logone River in Cameroon has resulted in ***significant drought damage*** to the 6,000 km^2 floodplain (Wesseling *et al.* 1995). The immediate impact has resulted in a major decrease in fish stocks as spawning and nursery areas have disappeared. Locally the impact has been

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[1] This is similar to predictions made for the Tana (Nippon Koei, 1995 - Environmental Assessment Report).

major, with fish catches reduced by as much as 90%, and the area of dry season pasture has been reduced.

In another similar sized floodplain in Zambia, the Kafue flats, the development of a downstream reservoir for hydropower with limited storage capacity and an upstream reservoir that was largely required to regulate the flow through the lower reservoir, but was also to release small floods to the downstream environment (described in Section 21.4.2). The main changes have resulted from a decrease in the seasonal flooded area with an increased area of permanent water (Sheppe 1985). During the flood season, before the construction of the dams, the area is described as having been dominated by extensive flooded areas supporting emergent grasses (*Echinocholoa stagnina, Oryza longistamina* and *Phragmites mauritianus*), the area is now predominantly either permanently under open water or permanently above the flood level. Thickets of plants that require permanently moist soil conditions are becoming established along the banks of the new permanent water features (*Cyperus papyrus* and *Typha domingensis*). Woody plants are now invading the areas permanently above the new flood levels including an introduced species *Mimosa pigra*. The floodplain grassland formerly supported large concentrations of wildlife, including Lechwe that feed ***in*** the shallow water utilising the flood grasses when they are most nutritious. The population of Lechwe decreased from around 80,000 to around 45,000 in 1981[1].

21.6.2 Socio–Economic Impacts

The economic impacts of reduced flooding are a direct result of the environmental impacts and are often the only real indicators of changes that are available. These changes are often reflected by a decrease in the options available to local communities in terms of possible economic activities. One way of quantifying the impact of reduced flooding is to put a value on water and sediment/nutrient input into the floodplain system, that is lost following river flow regulation[2]. The net loss to the floodplain in the Nile has been estimated as the free annual equivalent of 6,000 tons of potash and 17,000 tons of nitrogen, but this has been dismissed by some comentators as being insignificant given the change to intensified irrigated production systems relying on the continuous use of fertilisers.

One of the few cases where the potential negative socio-economic impacts of dam were acknowledged in advance, although not fully accepted at the design stage, was the Manantali Dam on the Bafing River in Mali, the principle tributary of the Senegal River (see Section 21.4.3). The downstream ***flood dependent*** communities were estimated to have a minimum population of around half a million[3]. The planned

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1 Clearly some of this reduction will be a result of increased human pressure, which in itself has been exacerbated through loss of other pre–dam economic opportunities.

2 In biological "economics", this sediment and water input can be viewed as a free dynamic energy input into the system, supporting primary production.

3 Estimates of the total basin population are in the region of 1.6 million, of whom 90% are dependent on arable farming, the rest are either fisherman or nomadic pastoralists.

downstream development included 375,000 ha of irrigation, but it was accepted that the development would not occur immediately and a temporary operating rule was adopted to release floods for a period of ten years, to continue to support the agricultural functions of the floodplain. specifically flood recession farming. The floods that were released were supposed to be sufficient to flood around 50,000 ha, which could not adequately compensate for the pre-dam situation of up to 250,000 ha.

The dam will however, produce one benefit that is indisputable, the generation of hydropower. The installed turbine capacity will eventually be capable of producing 800 GW per year, and even with flood release the total capacity would not be reduced below 600 GW per year. The demand for cheaper and more reliable energy is led by the major industrial urban centres, which form a less numerous but more immediate political power-base than the extensive rural populations. Additional political pressure is exerted from outside the countries through the donor agencies, as construction companies tender for dam and power line construction projects of a nature that have largely been abandoned in their own countries (Horowitz 1991).

The development of the upstream Manantali Dam and the downstream salt-water/level control Diama Dam, has raised water levels in the natural downstream lakes, depleted as a result of drought. Downstream, the "rehabilitated" lakes and newly created reservoirs will of course develop a lacustrine fisheries which can be expected to reach a final output of 6,700 tons per year, but at a cost of the loss of the previous floodplain fisheries which has been estimated to have produced in excess of 7,000 tons annually – i.e. a net loss of fisheries production. In addition the simple trapping techniques developed to highly efficient levels in the floodplains will have to be replaced by new systems dependent on boats and nets, at a higher investment cost. Similarly, at the coast the construction of the Diama Dam will create a new freshwater fisheries, but only at a cost to the existing estuarine fisheries. Upstream the total floodplain and river fish production has been estimated as having been around 45,000 tons, between the two dams the loss of floodplain is expected to reduce this catch by about 12,000 tons, although there will be a compensatory increase of 3 000 tons in the reservoir itself. This therefore represents a net loss of at least 15,000 tons annually throughout the system, and from OMVS's own figures increasing to an annual loss of 19,000 tons as further development takes place (Mounier 1982)[1].

The linkage between cattle management and floodplain and dryland grazing is complex. The floodplain provides a key element in the production system that allows for maximised use of the dryland grazing, and the loss of one component can not be compensated for by the development or improved management of another component. In any case, cattle densities are expected to increase as the development of irrigation takes place, much of it on land previously used for grazing, while the reduced

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[1] OMVS recognises many of these negative impacts and proposes the following: most obviously, the development of irrigation to replace flood recession farming; to substitute woodlots against the loss of 7 600 ha of levee forest and another 43 000 ha of groundwater woodland; to expand sea fishing to compensate for the loss of inland fisheries; to develop commercial ranching with irrigated pasture to compensate for the loss of flooplain pasture on which nomadic and semi-nomadic pastoralists depend.

flooding will lead to a decline in the quality and carrying capacity of the remaining pasture.

The irrigation itself, supposed to be an improvement on traditional farming systems, always requires further capital expenditure before it can start producing. Present investment costs have been estimated as being around $10,000 per ha[1]. The original rationale for irrigated agriculture was to a large extent based on the production of cash crops, predominantly cotton and sugar cane for export. The general slump in commodity prices, combined with increased competition from elsewhere, has largely undermined these original concepts. The traditional mixed, risk avoidance, farming systems will therefore be replaced with irrigated food crop production dependent on continued investments on imported inputs (fuel, pesticides and fertiliser), while generating little or no foreign exchange earnings. This degree of high investment farming, unless supported by highly efficient credit and other institutional and infrastructural services, precludes the poorer farmers, for whom the scheme was originally designed. There is therefore likely to be increasing consolidation of holdings, either directly or indirectly through indebtedness, by larger farmers, and an increasing pressure on the smaller poorer or landless farmers to migrate in search of work in urban centres.

Although much of the discussion has been based on African environments, the pattern of disruption to local communities is reflected elsewhere as socio-economic activities have adapted to the natural flooding regimes. The Tucurui Dam on the Tocantin River, Brazil, is expected to have similar environmental and hence linked socio-economic impacts downstream. The natural flow regime of the river includes extensive seasonal flooding in the middle and lower part of the basin (Barrow 1988). The natural and human production systems have evolved to exploit flooding; "*...to consider the regulation of flooding as a benefit... ...is misguided; wildlife and people are adapted to flooding, even dependent upon it.*" Flood recession farming has been reduced as the area of inundated levees and floodplains has been reduced. Water quality has changed, and the loss of sediment has been associated with reduced (success in) fish catches. The two main downstream economic activities have therefore been affected.

Although some of the primary impacts can be qualitatively described, the general lack of knowledge of the Amazonian situation, makes it difficult to predict in quantitative terms the overall impacts. In particular, the changed floodplain regime must have an effect at species level on the flora and fauna, in an area known to be particularly valuable from a bio-diversity point of view. Again, without more detailed information it is difficult to put a direct economic value on these products, but the majority of communities derive part of their living through the collection of plant products, including latex, nuts, palm hearts and timber.

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1 Bura is estimated to have cost in the region of $40,000 per hectare and, moreover, now requires rehabilitation.

21.6.2.1 Social Disruption

In most cases the downstream populations have born the costs of these upstream developments with no attempt to mitigate the negative impacts, apart from the few token endeavours to artificially create controlled floods to compensate for the loss of a natural flooding cycle. Despite the long-term and irreversible damage to the downstream societies, in most cases the reaction has been one of acceptance of reduced opportunities and living standards, and out-migration in search of other economic opportunities.

However, there have been exceptions to this, and again the development of the Manantali Dam in Senegal provides an example. The development of the dam was expected to be followed by the rapid development of irrigation, and as a result the floodplain – the future irrigated area – became highly attractive as a land investment. On the Mauritanian side, the Moorish elite took over land from the black communities along the river, which increased land pressure and hence competition between arable (flood recession) farmers and pastoralists, at a time when there were already problems as a result of the drought (Acreman 1994). To summarise the resulting conflict: 200 Wolof and Peul were killed in Nouakchott; in retaliation riots in Dakar led to the death of 35 Moors; 15,000 Mauritanians were put under military "protection"; and eventually 180,000 people were forced, as refugees, to leave the country, most of them to Senegal. As it turned out, little of the proposed 126,000 ha of irrigation proposed for Mauritania has ever been completed.

At a slightly different level, but still linked to the rather more formal land tenure arrangements that are associated with irrigation development (and resettlement), in Nigeria a total breakdown between the displaced and host communities and the scheme managers resulted in a major political crisis. The Bakalori Reservoir, on the Sokoto River, displaced a number of villages whose inhabitants were offered compensation for the loss of their farms, although it was not established where they would find alternative land suitable for farming in an already densely populated area (Beckman 1984). The Federal Government then decided that compensation should be on a land for land basis and offered them plots in dry upland areas, with soils so infertile and shallow that, even in this area of high population pressure these areas were not farmed. This form of compensation was rejected, and following the impounding of the reservoir, the displaced population either migrated or, rather more critically, moved in among the downstream communities. Within this downstream area, destined for irrigation development, large areas of farm land were destroyed as levelling work progressed and farmers were unable to cultivate for up to three seasons. Farmers began to defend their fields preferring the immediate return form their farm land to the indeterminate return from an incomplete irrigation scheme that might allocate their land to others. When land allocation finally started there was further disruption as farmers fears were born out and some were not allocated any plots while others had their plots drastically reduced[1].

In 1979 the conflicts reached a head, with the displaced farmers joining with those who were supposed to benefit from the irrigation, blockading the roads into the area. The Deputy State Governor met representatives of the community and assured them that compensation would be paid. However, nothing happened and resistance to further development continued into 1980. In April 1980, "mobile" police brought in from outside, entered the area. Following an exchange of fire in which it was officially recorded that 14 farmers were killed while another 15 farmers and four policemen were injured, the riot was put down, the number of dead was later increased to 19 and then 23. The actual circumstances leading up to this event and the real cost will probably never be known, but it is accepted that in addition to this "limited action" most of the villages along the routes into the area were burnt down, and hundreds of people arrested[2].

21.6.3 Environmental Tradeoffs

The concept of environmental tradeoffs has resulted from the acceptance among environmentalists and engineers that there are arguments on both sides of the development equation. The serious negative environmental impacts of large water projects have been clearly demonstrated, but so have the environmental and social benefits. The increasing demand for energy will have to be met by increased generating capacity; the increasing demand for water will have to be met by increasing storage capacity; and hydropower through the development of reservoirs provides a renewable and relatively low polluting energy source.

If potential negative environmental and/or social impacts are identified at the start of a programme, there is then the possibility of negotiating mitigation through alternative or additional developments as part of the overall hydropower programme. The early negotiation of tradeoffs will avoid delays in project implementation and, in the long term is likely to reduce overall project costs. Environmental tradeoffs can include both mitigatory development within the project area and parallel development outside the project area (Goodland 1987).

Goodland quotes four examples in which environmental tradeoffs have been considered, of which two could be regarded as successful. In Indonesia, the development of irrigation in downstream areas specifically included the creation and management of the Dumoga National Park which in itself protects the upper

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1 One of the contributing factors to the problems was that up to 40% of the total area had been lost from farming through infrastructural development, including canals, access roads, pumping stations and ground that proved to be outside the command area.

2 Even official figures give 187 suspected rioters arrested. The number of people killed is probably in excess of two hundred; a detailed list of 126 names has never been disputed by the authorities. Jouranlists were not allowed into the area.

catchment on which the irrigation itself depends[1]. In Australia, following considerable controversy, legislation was passed ensuring the continued protection of the Wild River's National Park and stopping development of the Franklin River hydroproject; two alternative dam projects were then negotiated downstream in less critical areas.

A third case quoted was the Silent Valley hydroproject on the Kunthipuzha River in Kerala, India. Work on this construction started in 1973, stopped in 1974, restarted in 1976, stopped in 1979, restarted in 1980 before being eventually suspended in 1980 at a cost of 3 million dollars. The main reason for the final decision was that there would be an irrevocable loss of 540 ha of valley floor tropical rainforest within the 8,950 ha of the Silent Valley reserve forest. Although it was proposed that this loss could be compensated for through the enhanced protection of other forest areas, it would be the loss of a unique forest habitat against the protection of a more extensive and different habitat.

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1 The Park protects a number of rare and threatened species; however, the Park has also had it's own impact through the resettlement of some 400 families who lived within the new boundaries.