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Dams and Large Scale Irrigation on the Senegal River. Impacts on Man and the Environment

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CASE STUDY FOR 2006 HDR
DAMS & LARGE SCALE IRRIGATION ON THE SENEGAL RIVER
IMPACTS ON MAN & THE ENVIRONMENT[1]

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Abstract

A case study is presented of the processes that led to and consequences from the construction of the Diama anti-salinity barrage and Manantali Dams on the Senegal River. Constraints to large scale irrigation were not adequately taken into account, while to date planned artificial floods to assure the continuation of traditional production systems (e.g., recession agriculture, freshwater fish production, estuarine/marine fishery nursery grounds and dry season forage) have been inadequate in both magnitude and duration. An environmental assessment identified most of the adverse impacts and recommended mitigative actions including the modeling of controlled floods. The consequences of ignoring and/or inappropriate mitigation resulted in the displacement of 10-11,000 people behind the Manantali dam with inadequate and less fertile lands, as well as adverse impacts on traditional downstream production systems used by between 500-800,000 people resulting in conflicts between traditional herders and farmers, and nearly war between Mauritania and Senegal. In addition, large scale commercial irrigation tended to turn peasant farmers into sharecroppers for local and outside elites. The majority of rural inhabitants are worse off as the result of this development program; under-nourishment, malnutrition, out-migration and remittances being prevalent. These are a common problems associated with dams across Sub-Saharan Africa, especially where floodplain ecosystems are dominant.

Key words: Dams, large-scale irrigation, floodplain ecosystem, artificial floods, mitigation

Introduction

About 27% of land (596,491,000 ha out of a total of 2,195,958,000 ha or 22 million km^2) in Sub-Saharan Africa has "no" or "*moderate constraints*" for crop production based upon climate, soil and terrain (FAO, 2003). However, not all of the 27% of the prime/high potential land may be available for agriculture being in other critical land uses such as parks and protected areas and/or their dispersal areas (IUCN goal 10% for all countries), critical wetlands, forests, or already degraded in over-populated areas such as Rwanda, Burundi, Highlands of Kenya and Tanzania, Southwestern Uganda, Ethiopia and much of Nigeria. As human populations in Africa increase, this is where the battle lines are drawn; what land will remain natural versus be converted to farm land? Thus irrigation becomes an interesting alternative for Sub-Saharan Africa.

Currently there are approximately 5.2 million ha in irrigation in Sub-Saharan Africa (Table 1) using only 2% of the renewable water supplies (FAO, 2002). FAO's (Food And Agricultural Organization Of The United Nations) definition of irrigation includes traditional floodplain recession agriculture, "*data on irrigation relate to areas equipped to provide water to the crops. These include areas equipped for full and partial control irrigation, spate irrigation areas, and equipped wetland or inland valley bottoms*" (FAOSTAT, 2004). If one discounts Madagascar with 1,090,000 ha and Sudan 1,950,000 ha in irrigation (FAOSTAT, 2004) only 2,185,000 ha was irrigated on the rest of the subcontinent in 2002.

Table 1: Actual irrigation in Africa & Sub-Saharan Africa

Irrigation Agricultural Area (1000Ha)	**Year**				
	1961	**1971**	**1981**	**1991**	**2002**
Africa	7,410	8,609	9,631	11,351	12,879
Africa South of Sahara	2,709	3,171	4,064	4,883	5,225

Source: FAOSTAT (2004). Includes islands of Madagascar, Mauritius and Sao Tome & Principe for both Africa and Sub-Saharan Africa

[1] This paper is part of a larger analysis that is under preparation.

The potential for irrigation along with "<u>*environmental constraints*</u>" is 42.5 million ha for all of Africa (FAO, 1997) (Table 2) or about <u>30,770,000 ha[2] for Sub-Saharan Africa</u>.

Table 2: Environmental impact assessment of irrigation, by basin in Africa

Basin	Irrigation potential (1000 ha)	Environmental impact hazard				
		Salinity	Health	Forest	Fishery	Wildlife
Senegal river	420	+++	++	+	+	+
Niger river	2 817	+++	++	+	++	++
Lake Chad	1 163	+++	++	+	++	++
Nile river	8 000	+++	+	+	+	++
Rift Valley	844	+	++	+	+	+
Shebelli-Juba	351	+++	+	+	+	+
Congo/Zaire river	9 800	+	+	++	+	+
Zambezi river	3 160	++	++	+	+	+
Okavango	208	++	+	+	+	+++
Limpopo river	295	++	++	+	+	+
Orange river	390	++	+	+	+	+
South interior	54	+++	+	+	+	+
North interior	71	+++	+	+	+	+
Mediterranean Coast	850	+++	+	+	+	+
North West Coast	1 200	+++	+	+	+	+
West Coast	5 113	+	++	+	+	+
West Central Coast	835	+	++	++	+	+
South West Coast	1 808	++	++	+	+	++
South Atlantic Coast	84	++	+	+	+	+
Indian Ocean Coast	1 500	+	+	+	+	+
East Central Coast	1 928	+	++	+	+	+
North East Coast	78	++	+	+	+	+
Madagascar	1 500	+	++	+	+	+
Islands	35	++	+	+	+	+
Total	42 504					

Source: FAO, 1997. +++: serious, ++: moderate, +: low or nil

[2] From Table 5.28 Subtracting off Nile River, North Interior, Mediterranean Coast, North West Coast, North East Coast, Madagascar, Islands

The construction of the Kariba Dam on the Zambezi River in the 1950s ushered in an era of big dam building on the African Continent. Most large dams in Africa were built upon the U.S. Army Corps of Engineers "*Integrated River Basin Planning Model*," epitomized by the creation in 1933 of the Tennessee Valley Authority (TVA) and the adoption of the TVA model by the United Nations in 1958 (Hitchcock, 2001 *In:* Miller, Cioc & Showers, 2001 & Ward, 2002). The idea was to approach river basin development in addressing the multifaceted development needs in an integrated manner from addressing electricity, urban and rural development, navigation, agricultural, fishing, recreational and cultural needs of the people living within these river basins.

Senegal River Basin

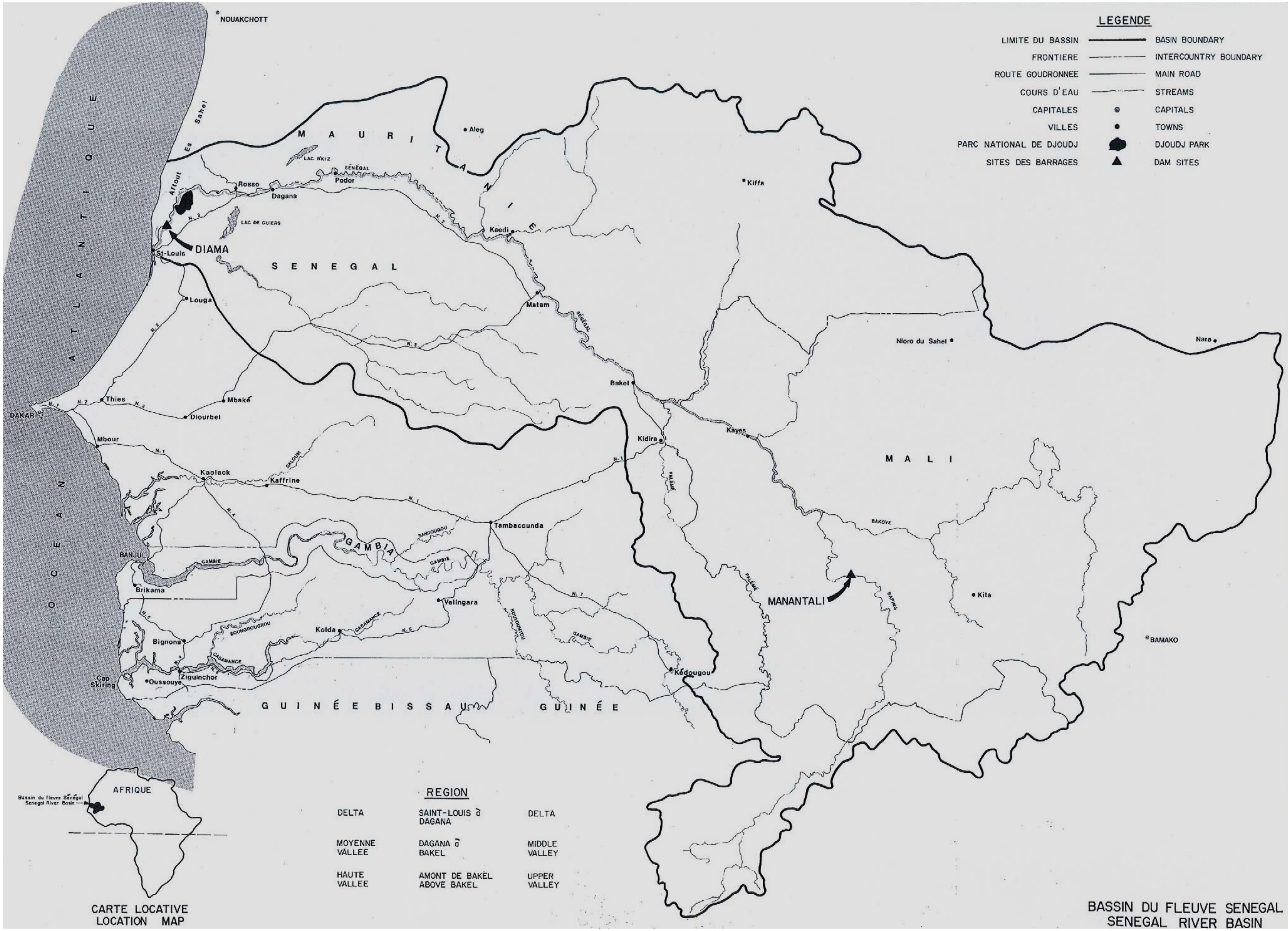
The Senegal River is the second longest river in West Africa, after the Niger River (4,200 km), with a length of 1,800 km and a watershed of 290,000 km^2 (Figure 1). The upper basin in western Mali and Guinea provides almost all of the river flow. No significant flows are added below the juncture with the Falémé River. Average annual precipitation is 2,000 mm in the headwaters (Guinean eco-climatic zone) and 250 mm in the northernmost area of the basin (Sahelian eco-climatic zone). The average annual discharge at Bakel, which measures accumulated flows from these headwaters, is 770 m^3/sec. The average monthly maximum and minimum flows at Bakel are 3,500 m^3/sec in September and 10 m^3/sec in May (Gould, 1981).

In the 1970s, the Valley was to be *'le grenier du Sénégal'*, Senegal's granary (Adams, 2000a). However, the Sahelian drought of the 1970s resulted in the creation of the '*Organisation Pour la Mise en Valeur du Fleuve Sénégal' (OMVS*) or Senegal River Basin Authority on March 11, 1972 by the governments of Mali, Mauritania and Senegal in order to promote irrigation, power generation and navigation in the Senegal Valley. The goal was to provide enough water to achieve the following development objectives (GFCC, 1980a):

- Irrigate 255,000 ha according to GFCC (1980a). Others use the figure of 355,000 ha (Bosshard, 1999); and even 420,000 ha (Table 2). This latter figure is close to an average flood of 459,000 ha as calculated by GFCC (1980b),
- Produce hydropower (800 GWh (Gigawatt hours)/year) (GFCC, 1980a),
- Make the river navigable all year round between Saint Louis at the river mouth and Ambibédi in Mali,
- Supply freshwater for the *Lac de Guiers*, which is a source of the freshwater supply for Dakar, the capital of Senegal (Diop, Nakamura, Smith, & Khaka, 2000),
- Availability of surface water for annual recharge of Lac R'Kiz and Aftout es Sahel In Mauritania to create an artificial estuary,
- A year round flow of 100 m^3/second in excess of irrigation and other requirements to provide water depths needed for navigation (GFCC, 1980a).

This required the construction of two dams, the Diama Dam, an anti-salinity barrage 27 km upstream of the Senegal River mouth between Senegal and Mauritania, and the Manantali Dam is located in the Upper Valley in Mali, about 1,200 km upstream from the river mouth on the Bafing River, the main tributary of the Senegal River, which supplies approximately 50% (GFCC, 1980a) to 60% (Adams, 2000a) of the annual flow of the Senegal River. Diama was completed in 1986, and Manantali in 1988; both dams were inaugurated in 1992.

In terms of hydropower, the inhabitants of 30 villages, who were resettled downstream just a few kilometers from a dam that would be providing power for cities as far away as Nouakchott and Dakar, have no electricity (Baxter, 2001). This is typical of hydropower programs across the sub-continent, where power mainly fuels industry and urban centers, passing over the heads of the rural poor, the very people directly impacted by the development scheme. In June 1997, despite serious environmental and socioeconomic concerns raised by a host of critics, the World Bank approved a $US 38 million loan to help finance installation and operation of the dam's turbines. As noted, the Bank was not a lender for the original construction of the dam. The plan was to increase power output at the expense of other uses, with hydropower having first priority when reservoir levels fell (Pottinger, 1997). Electricity from the Manantali would supply 52% of production to Mali, 15% to Mauritania and 33% to Senegal (Baxter, 2001) and was to be operated and maintained by ESKOM Enterprises of South Africa, which has a 15 year contract (Bond, 2002). Many are concerned that this spells the end water being made available for controlled flooding to maintain ecological and traditional food production systems.

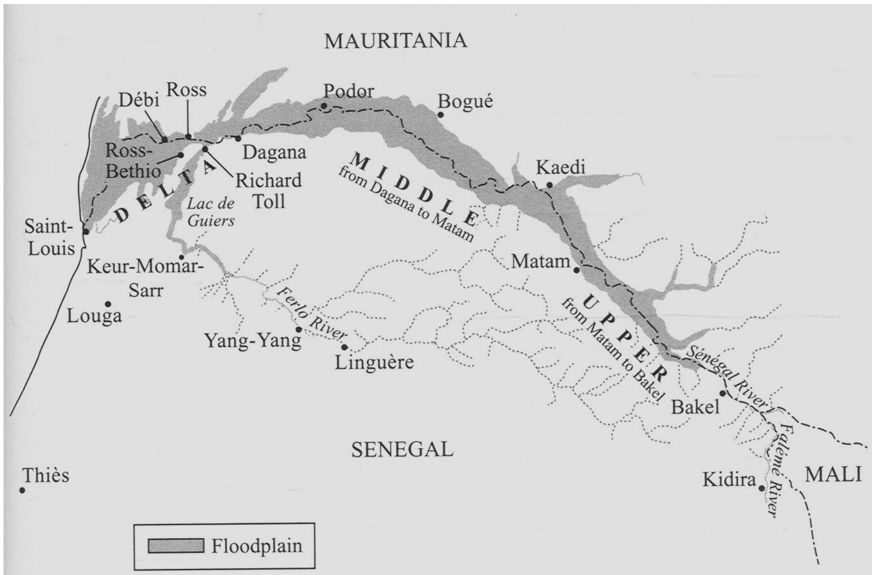


Source: Gannett Fleming Corddry & Carpenter

Figure 1: Dams in the Senegal River Basin

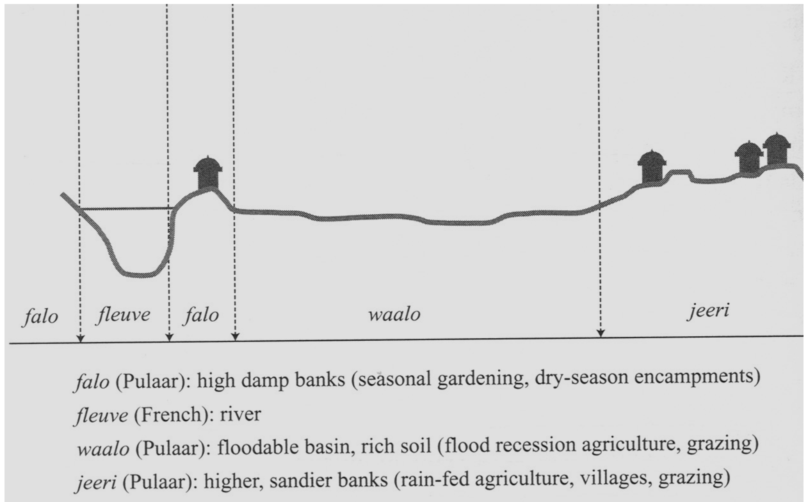
Senegal River Hydrology

For centuries, the annual floods of the Senegal River have been the lifeblood of flood recession agriculture, fishing, and cattle grazing for hundreds of thousands of people (Figure 2).



Source: Boone (2003)
Figure 2: Senegal River floodplain

The rainy season in the upper watershed traditionally occurs between June to October and results in downstream flooding between July and November (Gould, 1981). Traditionally, flooding occurred primarily downstream of Bakel in the Middle Valley, an alluvial plain 10-20 km wide and in the Delta, the lower 200 km of the river (Gould, 1981). According to Boone (2003) in the Middle Valley flooding occurred along a 600 km (360 mi) stretch of the river just below Bakel, with floodplains being as wide as 20 km (12 mi) in the Middle Valley, from Dagana to Matam (Boone, 2003). FAO (1997) estimates that prior to the dams "*the floodplain of the Senegal stretches up to 30 km in width, and runs 600 km downstream of Bakel. It covers a total of about 1 million ha and supports farmers, pastoralists and fishing communities. Up to half a million people depend on the flood-related cropping in the 'waalo' land of the floodplain*" (Figure 3). The floods provided nutrients to the floodplain and coastal fisheries, and recharged the aquifers upon which villagers depended for their domestic water supplies. Retreating floodwaters enriched the soil by depositing nutrient-rich silt on the land.



Source: Boone (2003)

Figure 3: Cross-Section of Middle Valley, Senegal River showing makeup of traditional agriculture

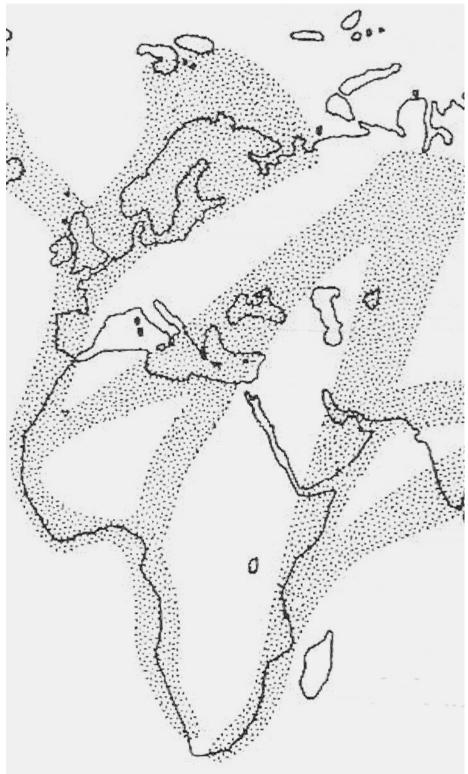
During the flood period the main river channel exhibited typical riverine (lotic) characteristics from the beginning of the rains until February. During this period of active flow, isothermal conditions were approached due to the complete mixing of the water column by turbulence. Sediment entering from runoff in the upper watershed was transported downstream greatly reducing the penetration of light into surface waters.

During the dry season, the river was navigable to Podor, 320 km upstream from the River Mouth (Gould, 1981). From the onset of the dry season in November until the beginning of the rainy season in mid-July, the lower portion of the river became increasingly estuarine as the salt tongue pushed upstream from the ocean to Richard Toll and sometimes as far as Dar Salaam, 218 km upstream from the mouth at Saint-Louis. These waters were greatly influenced by tidal action. In February, from Kaedi upstream, the river began to develop lentic (lacustrine or lake-like) conditions. This ponding effect reached a peak in late June and early July just before the rainy season (GFCC, 1979).

With the Manantali Dam in place, it was estimated that flooding would be reduced from 459,000 ha during an average flood in 1980 (pre-dam) to 190,000 ha by 2028 under full development of irrigation, hydropower and navigation (GFCC, 1980b). An artificial flood was planned for 15 years to assure inundation of 100,000 ha of land for flood recession farming, after which it would be stopped as irrigation took over (GFCC, 1980a). Plans for a regular and predictable artificial flood have never been achieved.

Impacts of Dams and Irrigation on Wildlife & Livestock, Senegal River

Very little of Sub-Saharan Africa's revered mega-fauna is left along the Senegal River Valley, while remnant populations exist in the headwaters of Mali. However, the world renowned Djoudj National Bird Sanctuary, a UNESCO (United Nations Educational, Scientific And Cultural Organization) World Heritage Site, is a major wintering ground for an estimated 3 million birds coming from Europe and Asia (Figure 4) and along with resident birds comprise about 300 identified species (UNEP-WCMC, 2002). Certainly, the major loss of floodplains has had a long-term adverse impact on migratory birds, though no quantitative data is presented.



Source: Loth (2004a)

Figure 4: Migratory bird movements coming into Africa demonstrating major route through Lake Chad/Chari-Logone floodplains

Le Houerou & Hoste (1977 *In:* GFCC, 1980c) found that in the Sahel the area required to support one Tropical Livestock Unit (TLU) of 250kg was:

- 12.72 ha in areas with <250 mm rainfall.
- 6.35 ha with 251-500 mm rainfall.
- 3.17 ha with 501-1,000 mm rainfall

At the time of the GFCC (1980c) study the load was 8.96 ha/TLU in Senegal, with no figures for Mali or Mauritania.

Along the Senegal River and throughout the Sahel, nomadic pastoralists and their livestock disperse from the floodplains during the rainy season and return during the dry season. During the rainy season the herds move north on the Mauritanian side and south into the interior on the Senegalese side of the river to exploit the highly nutritious pastures and to avoid the disease vectors in the flooded valleys. The timing of their return to the floodplains depends upon the intensity and extent of the year's rainfall and therefore of the available pasture outside of the wetlands. In bad rainfall years the floodplains are virtually the only refuge, allowing the animals to survive until the next rains (Hamerlynck, *Duvail & Ould Baba,* 2000).

Reduced flooding and dikes for irrigation have reduced traditional grazing lands from 80,000 ha to 4,000 ha in the Valley (GEF, 2002). Using the above estimate of 8.96 ha/TLU this means that there would be a reduction from 8,928 TLUs to 446 TLU on the floodplains at a minimum. The impact is likely greater if, in fact, with the Manantali the average annual flood of 459,000 ha (GFCC, 1980b) has been reduced to 30,000 ha, with inadequate water every 3rd year for adequate flooding and flooding reduced from 4 months to 2 weeks (Bosshard, 1999). If much of this floodplain is available for dry season grazing the reduction would be from 51,228 to 3,348 TLUs at a minimum. The carrying capacity of these floodplains is likely to be much higher, than the average ha/TLU given above so that the impacts would be much more dramatic as likely hundreds of thousands of livestock concentrate along the river during the dry season to take advantage of this extremely productive environment. If an estimated 300,000 head of cattle concentrate on the Gambia River floodplains (Carney, 1984 *In:* Samba & DeGeorges, 1987a & 1987b) that total 158,000 ha (DeGeorges, 1987) that are orders of magnitude smaller than those of the Senegal River then 2-3x this number might use the Senegal River floodplains during the dry season. In the Senegal portion of the Senegal River Basin alone, GFCC (1980c) estimated livestock loading in the pre-dam period to range between 566,000 to 742,000 TLUs ranging over 6,649,500 ha, which was believed to be conservative. A large portion of this livestock would likely end up along the floodplains of the Senegal River during the dry season, while some might migrate southwards feeding on crop residue in farming areas.

In addition to losing forage, veterinary issues also arose as a result of the dams. The permanent presence of stagnant fresh water behind the Diama Dam favored the development of parasitic diseases affecting livestock, especially liver flukes. These ailments were rare in the Delta prior to the Diama and are now very common. They have a major impact on livestock productivity. Herders have to expend major efforts to keep livestock from entering the infested waters and to provide drinking water away from the river's edge. The epidemic of rift valley fever, which occurred at the filling of the Diama reservoir, probably a one off event, also caused great losses to livestock from abortions (Hamerlynck, *et al*., 2000).

Impacts of Senegal River Dams on Floodplain "Recession" Agriculture

"*Traditionally, the parts of the floodplain that had been under water for 45 days at least could be cultivated without any other intervention but planting seeds when the waters receded. Fertility was maintained by the clays and silts that sedimented from the floodwater, and by the dung left by animals that had grazed the floodplains during the dry season. Though the productivity per ha rarely exceeded 1 ton per year, the low labor and capital input and the hundreds of years of experience transmitted through the generations made this exploitation system rather performant, especially for the rural poor. Even now, sedentary agriculturists that have converted to rice farming continue to practice recession agriculture as an extra source of food security whenever the floods released from Manantali allow. A major problem is that the land available for this sustainable type of agriculture is insufficient, not only because of population growth and reduction of flood height but also through the change in land ownership structure. Many of the best soils have been converted to large-scale irrigation plots and concomitantly their ownership has 'moved out of the valley' (that is taken over by rich outsiders who can afford inputs). This has in some cases led to serious social conflict. A positive development has been the establishment of small-scale market gardening along the new permanent freshwater courses*" (Hamerlynck, et al., 2000).

The Institute of Development Anthropology (IDA), which in 1987 began a program of research in Senegal, the Senegal River Basin Monitoring Activity (SRBMA) demonstrated that flood-recession crops offered a better return on capital and labor than irrigated farming, while reducing risks to a minimum. They suggested that a permanent artificial flood from Manantali raising the river to the level achieved by a natural flood was justified by the increased production, income and work it would provide, while also protecting the environment. Contrary to what OMVS consultants had claimed, there was no incompatibility between controlled flood releases and the production of electricity.

In 1997 an artificial flood was released close to the hydrograph used as a standard. Satellite images suggest that the area available for flood-recession farming was on the order of 70,000 ha, 45,000 ha on the left bank and 25,000 ha on the right bank. A rapid survey of SAED (Société d'Aménagement et d'Exploitation des terres du Delta du Fleuve Sénégal – controlling irrigation on the Senegal River on the Senegalese side) agents and people living near major areas of flood-recession land suggested that this flood was generally satisfactory, although it was sometimes judged not to have lasted long enough for satisfactory flooding of low-lying land. It was an improvement over 1996, when there was scarcely any flooding, but distinctly inferior to that of 1995 (Adams, 2000b).

The other problem is the irregularity in flooding. With no announcement the Diama would be opened and drained encouraging people to plant maize, beans, calabashes and pumpkins along the banks only to see their work destroyed by a release of water from Manantali (Adams, 2000a). In both 1989 (Adams, 2000c & Adams 2000c) and 1991(Adams, 2000c) two artificial floods in the same year wiped out farmers' crops planted after the passing of the first flood. OMVS's lack of respect for its promise to maintain an artificial flood, is particularly striking as the Senegalese Government's position on this matter seemed to have evolved (Adams, 2000a).

The Institute for Development Anthropology, about 1998, assessed the following operational scenarios for the Manantali/Diama Dams using a minimal flow at Bakel required for a flood, where all rivers join, as 2,500 m^3/second (Adams, 2000b & Adams, 2000c):

- *Scenario 1* gives priority to the needs of agriculture (irrigated and flood recession),
- *Scenario 2* gives priority to electricity generation and the needs of irrigated agriculture (with no flood support),
- *Scenario 3* takes into account the three main objectives of the dam (supplying water for irrigation, generating electricity, and flood support in favor of flood-recession farming).

Based upon natural flows for the period 1970-93, which correspond more closely to present circumstances, Scenario 3 would allow 50,000 ha of flood recession farming one year in ten and 40,000 ha every other year. This compares to 50,000 ha of flood recession farming one year in three without dams (Adams 2000b & Adams, 2000c). "*Scenario 1 yields results very close to 3, because when the river's rate of flow is weak (as during the period under consideration), there are few releases which cannot be used for energy production"* (Adams, 2000b). Scenario 2 would not allow for any artificial flooding.

This compares to the annual average flood of 459,000 ha modeled by GFCC (Gannett Fleming Corddry and Carpenter). Over the period 1946-1971, it is estimated that on average 312,000 ha were of low lying land, *waalo,* was flooded every year on both banks of the river, and 108,000 ha cultivated; on the Senegalese side of the river, 65,000 ha were cultivated (IRD-OMVS, 1999 *In:* Adams, 2000c), meaning an average of 43,000 ha cultivated on the Mauritanian side. Seck (1991 *In:* Boone, 2003) estimates that for an average flood only 100,000 ha was cultivated on both sides of the river.

The artificial flood would in no way support the estimated 364,132 persons out of a total population of 592,602, who were engaged in flood-recession farming (Adams, 2000d).

According to Acreman, Farquharson, McCartney, Sullivan, Campbell, Hodgson, Morton, Smith, Birley, Knott, Lazenby, Wingfield & Barbier (2000) since 1991, floods have been broadly in line with a hydrograph designed to flood 50,000 ha, and exceeded it in years of good rainfall, while avoiding damaging second peaks, averaging 58,000 ha under recession cropping, an increase over drought years before the dam. Available pasture has been significantly reduced. There is no discussion over the duration of the flood, important for groundwater recharge, fishery production, among other factors, nor the quality of nutrient rich sediment that is deposited on the floodplains.

The continuation of an artificial flood will require 1) Political will and 2) Specific instructions from the OMVS to the private operator (ESKOM South Africa) of the Manantali Dam requiring the allocation of water for such purposes on an annual basis. Uncertainty remains about the will of the member states to maintain the artificial flood, a suspicion confirmed by OMVS's pursuit of the navigation component of its program, a year-round water level requiring water in excess of that required by irrigation (Adams, 2000b).

There is a fundamental choice to be made in agricultural policy for the Senegal River Valley, between striving to make the dams generate revenue from electricity, large scale irrigation and river transport, or using them to ensure the survival of downstream family farming and related activities (e.g., flood recession agriculture, dry season forage, freshwater and estuarine fisheries). This debate has not taken place, and if the debate does not take place now, the question will not be resolved once and for all, and the losers from the Manantali Dam will have lost out forever (Adams, 2000b). Ideally, there will be a need for a degree of compromise on both sides, hopefully assuring the long-term viability of natural production systems.

Impact Of Senegal River Dams On Irrigation

Senegal River

On the Senegal River*, the Société d'Aménagement et d'Exploitation des terres du Delta du Fleuve Sénégal* (SAED) was the state parastatal tasked with oversight of irrigation development in the Senegalese portion of the river. It had begun working with small-scale irrigation, further north on *périmètres irrigués villageois'-PIV* (villager irrigated perimeters), which developed rapidly in the Valley on the Senegalese side increasing from 20 ha of irrigated land in 1974, to 13,000 ha in 1986 (Adams, 2000a) and 18,000 ha by 1988 at 700 sites (Boone, 2003). Yields were good. Had it not been for OMVS and the Senegalese government's plans of dam building and large scale hydro-agricultural schemes, there might have been a small chance of PIV's success influencing River development plans, which might have enabled it better to weather the storms of the 1980s (Adams, 2000b). Boone (2003) explains that the PIV system was begun by peasant farmers in the Upper Valley using motor pumps to draw water from the river to land above the normal floodplain that was not controlled by the Soninké elite even though much of the floodplain was uncultivated. In 1976 the Government of Senegal intervened to centralize control through SAED to develop rice producing PIVs along the Upper and Middle River. The average household plot size in a PIV was 0.25 ha. In a power sharing relationship with central government, control over tenure was conceded to the ruling Fouta (Toucouleur) oligarchy in the Middle Valley and Soninké oligarchy in the Upper Valley. This was despite the fact that the 1964 National Domain Law over land tenure abolished "*traditional landholders*" to free peasant farmers from bondage by the rural elite. The rural elite took over control of the PIV's who benefited from credit and subsidized agricultural inputs. At the same time they retained their traditional control over the floodplains. SAED was to deduct the cost of inputs after buying the rice harvest from farmers. However, most farmers consumed the produce themselves and/or sold the rice on local informal markets, SAED commercializing not more than 35% of the rice produced in the Upper and Middle Valley. Costs on the small plots within the PIV proved to be too high to make this commercially viable (Boone, 2003). The peasant families who had lived in the Senegal valley for many decades could often not afford the inputs needed for irrigation farming (Bosshard, 1999). Between 1985 and 1990 SAED withdrew producer subsidies and PIVs were abandoned, leaving farmers even more vulnerable due to the disruption of flood recession agriculture by the Manantali Dam. This forced many farm families in the Middle Valley to depend upon rotational migration to Dakar (living on remittances), commercial activities and wage employment in the Delta (Boone, 2003).

SAED created an artificial peasantry in the Delta that was socially heterogeneous. Due to organizational (little autonomy to farmers) technical (high saline groundwater tables) and operational (farmers' refusal to reimburse debts, delays in delivery of inputs, poor maintenance of infrastructure problems), as well as high production costs of irrigation, irrigation has never taken off as planned (Boone, 2003). At a cost of $US 25,000-40,000/ha, the construction of large-scale irrigation networks fed by the Manantali reservoir proved to be more expensive than originally planned. Instead of 375,000 ha, only about 100,000 ha have been brought under irrigation so far, with only about 2,000 ha/year added (Bosshard, 1999). According to SAED's own statistics, the total area laid out for irrigation on the Senegalese bank of the River, was 71,751 ha in 1995; and the area actually farmed that year, in all seasons, was 29,792 ha (Adams, 2000d).

Between 1980 and 1987 as the Senegalese government gradually pulled back from managing large-scale rice estates in the Delta, there was a speculative land rush by Dakar *functionaires*, Mouride marabouts, merchants and SAED technicians eager to make a profit before salinization set in. From 1981-83, 40% of the requests for land grants around Lac de Guiers were made by persons residing outside of the rural council areas along with local '*peasant aristocracy'* such as village chiefs, and presidents of cooperatives. Gradually peasant associations made similar requests but appeared to lack little political clout (Boone, 2003). In the Lower Valley (Delta), peasant farmers were sometimes forced into sharecropping arrangements with prosperous outsiders. With irrigation, the traditional sorghum crop was replaced by rice. Even for the richer farmers, however, irrigation proved to be more cumbersome and less productive than the project planners had expected. Since there has been no electric power (until 2001), expensive diesel for running the pumps (as well as seeds and pesticides) had to be purchased. Once Senegal, where most of the irrigated land is situated, underwent structural adjustment in 1986, the government could no longer afford to subsidize inputs or credits. The harvest from the Senegal River Valley could not compete with rice imported at world market prices (Bosshard, 1999).

This problem was supported by similar conclusions about irrigation on the Senegal River examined as a means of assessing potential viability just south on the Gambia River. In the early 1980s the rapid deterioration of infrastructure and irrigation equipment on the Senegal River resulted in a rate of abandonment about equal to the rate of expansion. Likewise, the cropping intensity for those perimeters in irrigation in 1983 was estimated at 122% well below the projected rate of double cropping (200%), (University of Michigan, 1985).

The environmental assessment (GFCC, 1980a) was fairly accurate in its predictions on the loss of dry season forage, recession agriculture, and fish production, but failed to adequately take into account that 1) Pumped irrigated rice faced major environmental constraints (e.g., high saline groundwater table) and was likely not economically viable, and 2) Rice could be imported cheaper from Asia than grown by pumped irrigation in the Senegal River Valley, especially the Delta (Rosenblum & Williamson, 1990).

Manantali Dam Impoundment Fisheries

Projected fish yields from the Manantali Reservoir using the morpho-edaphic index (MEI)[3] graph from Henderson, Ryder & Kudhongania, (1973 *In:* GFCC, 1980d) predicted between 65-86 kg/ha/year of fish. Using more recent morpho-edaphic indices formulas from Henderson and Welcomme (1974) and Schlesinger & Regier (1982), estimates would range from 13-21 kg/ha/year. Since the Manantali Reservoir surface area would vary between 477-275 km^2 depending on operational level (GFCC, 1980a), maximum fish yields would likely vary between a low of 358 metric tons/year to a high of 4,102 tons/year, depending on average operational level and ultimately the long-term productivity of the reservoir. Fish catches in the Manantali reservoir cannot be considered a compensation for the losses in the rest of the Senegal River Valley.

Impacts on Floodplain and Estuarine Fisheries, Senegal River

During the wet season, from August through December, the Middle Valley exhibits characteristics of a freshwater fishery, relying upon inundation of the floodplains to replenish the fish stock by providing habitat for breeding and a nursery for various species. During the dry season, the river waters gradually subside, forcing the fish populations to leave the floodplain and concentrate in the main channel. All freshwater fishes caught are consumed, including zero-age class fish (under one year of age). The more important families of freshwater fish consumed include Osteoglossidae, Mormyridae, Characinidae, Citharinidae, Claridae, Schilbeidae, Bagridae, Mochocidae, Cichlidae and Centropomidae (GFCC, 1980d).

Traditionally before the Manantali and Diama Dams, with the receding waters of the rainy season, a salt wedge developed moving up the river from the mouth as far as the Doué Marigot at Podor, 320 km upstream from the River Mouth. The estuarine conditions created by this phenomenon were critical to fishes whose life cycles were tied to the salinity regime. These fishes included important species such as *Ethmalosa fimbriata* (African Shad), *Tilapia guineensis, Saratherodon melanotheron heudelotii, Mugil spp*., and Lisa *spp.* The African shad, while only a small contributor to the commercial marine fishery, was important in the artisanal fishery at the mouth of the Senegal River. Invertebrates whose life cycles are tied to estuarine conditions include the crab, *Callinectes spp.* and the shrimp, *Penaeus duorarum* (GFCC, 1980d & 1980a).

The Manantali Dam affected these vital functions, and reduced fishing significantly. Even fishing families are reported to eat imported fish now. The hydropower project will further impair fisheries in the floodplain and the coastal sea (Bosshard, 1999). This loss has been very extreme in the formerly estuarine part downstream of Diama and probably this has also impacted on marine fisheries through the loss of nursery functions for mullets (Mugilidae), shrimp (Penaeidae), shad (*Ethmalosa fimbriata*) and other species having an obligatory estuarine life history stage (Hamerlynck, *et al.,* 2000).

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[3] Morpho-Edaphic Index relates Surface Area, Volume and average depth as indicative of the abundance of the shallow littoral zone and thus age of lake (e.g. young/oligotrophic and old/eutrophic) as well as indirectly habitat and productivity, along with conductivity or total dissolved solids as an indication of nutrient abundance and potential primary productivity to support fish populations.

Before the construction of this anti-salt barrage, the area was nevertheless of great economic importance as a nursery grounds for numerous commercial marine fishes that spent part of their life cycle in the brackish estuary. Traditionally, mullets migrated at the beginning of each early dry season from the Banc d'Arguin National Park in the north of Mauritania to the Senegal River Delta to spawn (Kapetsky, 1981 *In:* Binet, LeReste & Diouf, 1994, & Kloff, 2002) and coastal lagoons (Kapetsky, 1981 *In:* Binet, LeReste & Diouf, 1994). In the sixties abundant juvenile mullets were observed by a team of French and Mauritanian researchers at Rosso lying 80 km upstream of the present Diama Dam, which is 27 km upstream from St Louis near the mouth of the river – thus 107 km upstream from the river mouth. With the Diama Dam, the nursery area became greatly reduced due to the obstacle the dam posed for migration of marine fishes, and even worse the remaining area downstream of the dam deteriorated as a nursery due to a lack of fresh water and resulting hypersaline conditions (Kloff, 2002).

During the dry season no freshwater was released by Diama into the former estuary, which becomes gradually hypersaline in the course of each dry season (Kloff, 2002). Juvenile fishes die due to the high salt concentrations. Ten years after the construction of the Diama Dam the mullet fishery sector - a multimillion dollar business through the export of eggs "*poutargue*," a form of caviar, to Southern Europe - in Mauritania completely collapsed. Although over-fishing is believed to be one of the major factors, the deterioration of the former estuary is believed to have significantly contributed to the catastrophe (Kloff, 2002).

According to Binet, *et al.* (1994), the anti-salt barrage, designed to preserve agricultural land from salty water and to make them irrigable, blocks the outflow of freshwater to the sea except during the heaviest flooding. The Diama also prevents migrations of anadromous[4] species (e.g., mullet, shrimp & shad), and particularly the upstream movement of euryhaline[5] species (e.g., shrimps, crabs, oysters). The freshwater species carried down toward the estuary by the floodwaters will no longer reach their destination and catadromous[6] species will be unable to spawn in the brackish waters. Major mortalities of migratory species are observed at certain times. However, the feared elimination of the *bonga*/shad (*Ethmalosa fimbriata*), *Callinectes* (crab) and the pink shrimp in the Senegal River estuary did not take place. Lastly, the irregular nature of water releases and hence of downstream phytoplankton surges have increased the "*unpredictable*" nature of this environment, favoring colonization by opportunistic species of low commercial value. Indeed, an increase in the relative numbers of *Tilapia* and mullet has been observed.

There seems to be some contradiction. However this is not believed to be the case, if one looks at what happened as a result of the 1970s drought in the creation of "*natural*" hypersaline conditions in the Siné Saloum and Casamance Estuaries. In the Siné Saloum estuary – just north of the Gambia River and south of the Senegal River, where hypersaline conditions appeared to favor *Ethmalosa*, mullet and *Tilapia* over other species, there still was a major reduction in artisanal catches, including these species, during the drought period of the 1970s/early 1980s. Fish catches in the Department of Kaolack – Siné Saloum fell from a high of 4,000 metric tons in 1975 to a low of about 1,000 metric tons/year in the early 1980s. It should be noted that even though dominant in the catch, the *Ethmalosa*, yields dropped from a high of 829 tons in 1975 to a low of 40-70 tons in the early 1980s in the Siné Saloum. Mugil species, likewise while relatively speaking surviving the hypersaline conditions, dropped from a peak of 1,070 tons in 1975 to lows of 200-300 tons/year in the early 1980s in the Siné Saloum (DeGeorges, 1985). This also appeared to be the case for the Casamance Estuary just south of the Gambia River (DeGeorges, 1985) where the same 3 genera were dominant and where these species became dominant as one moved upstream towards more hypersaline waters, in places exceeding 170 ppt. (parts per thousand), the sea being 35 ppt. The Bas Delta study before the Diama Barrage, but impacted by the drought, showed similar results. With the drought and increasing hypersaline conditions most species fell out of the catches, with the dominant ones being (DeGeorges, 1984):

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[4] Anadromous fish species spend their adult lives in the sea but swim upriver to freshwater spawning grounds to reproduce

[5] Euryhaline species live in a wide range of salinities as opposed to stenohaline species restricted to a narrow range of salinities

[6] Catadromous fish species migrate from fresh water to saltwater to spawn

- The African Shad, *Ethmalosa fimbriata*
- *Tilapia/Saratherodon*
- *Penaeus notialis, etc* – Shrimp
- Two species of mullet (Mugilidae)

These are the same 3 genera/families of fish that became dominant in the Casamance and Sine Saloum. Attempts are underway to create an artificial estuary to address this issue backed by the IUCN (International Union for The Conservation Of Nature = World Conservation Union) (DeGeorges, 1984, Acreman, *et al., 2000,* Hammerlynck, *et al.,* 2000, Kloff, 2002 & Hamerlynck, *et al.,* 2001). There should be no delusion that creation of an artificial estuary of what appears to be about 16,000 ha might replace that which would be lost on both sides of the river, amounting to 100s of thousands of ha of aquatic habitat. On the Mauritanian side of the estuary, concern exists that development is resulting in in-migration of people to take advantage of improved fishing, pasture and agriculture resulting in overuse of the limited resources. Concern exists that the Diawling Park may become a green fleck surrounded by agricultural land (Hamerlynck*, et al.,* 2001)

GFCC (1980a) projected changes in fish yields from proposed development as follows based upon estimates of traditionally floodplain fish yields averaging 50-60 kg/ha flooded per year (GFCC, 1980a) (Table 3):

Table 3: Annual fish harvests in the Senegal River Basin before and projected harvests after various levels of proposed development, assuming annual average flood

	Metric Tons Fresh Fish/Year							
Year	**Lac de Guiers**	**Lac R' Kiz**	**Aftout– es-Sahel**	**Diama Reservoir**	**Senegal R. Estuary**	**Manantali Reservoir**	**Floodplain**	**TOTAL**
1978[7]	2,250	------	5	7,500	4,000	-----	33,000	46,755
1986[8]	2,750	1,200	5,000	4,500	------[9]	4,000	31,800	45,250
1987[10]	2,750	1,200	5,000	4,500	Same -	3,000	20,400	37,850
2002[11]	2,750	1,200	5,000	4,500	Same	3,000	19,200	35,650
2003[12]	2,750	1,200	5,000	4,500	Same	3,000	13,800	30,250
2028[13]	2,750	1,200	5,000	4,500	Same	3,000	11,400	27,850

Source: GFCC (1980a)

The fact is that the artificial flood of 100,000 ha/year, planned for a 15 year period following the completion of the Manantali Dam, has not been maintained. Fish production in the river and estuary has dropped by 90% (GEF, 2002). The annual flood with hydropower now on line is estimated at 30,000 ha/year, and of very short duration (a couple of weeks as opposed up to 4 months). Even without

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[7] Present Conditions,
[8] Diama Dam completed, Estuary fishery is lost; increase in harvests occur due to recharge of natural impoundments (Lac R'Kiz and Aftout-es-Sahel), some floodplain lost to agricultural development
[9] Estuarine Fishery as it presently exists is destroyed. 1987-2028 the same.
[10] Manantali complete. Significant loss of floodplain fishery due to decrease in magnitude & duration of natural flooding, and continued agricultural development; some flooding maintained artificially (100,000 ha/yr). In Manantali Reservoir, initial flush of nutrients results in peak fish production followed by a drop and then stabilization of fish production as primary productivity levels off, typical of impoundment fisheries.
[11] Same as in 1987 with continual loss of floodplain due to agricultural development.
[12] Discontinuing artificial flooding of 100,000 ha/yr results in significant loss of floodplain.
[13] Same as 2003, with continued loss of floodplain area due to agricultural development.

quantitative data, freshwater fish production must be extremely low (Bosshard, 1999). Both estuarine and floodplain fisheries have been significantly reduced. Only 16,000 ha of the artificial estuary have been put under management (DeGeorges, 1984, Kloff, 2000 & Hamerlynck, Duvail & Old Baba, 2001), whereas to reach the Aftout-es-Sahel would require the inundation of 35,000 ha (DeGeorges, 1984). No reference can be found to artificially flooding Lac R'Kiz so it is assumed this has not happened. Invasion by aquatic plants seems to be affecting fish yields on Lac de Guiers and the Diama reservoir. If one tries to reconstruct an estimate of fish yields today we would get (Table 4):

Table 4: Projected fish harvests based upon review of literature after construction of the Manantali and Diama Dams, Senegal River

Year	Metric Tons Fresh Fish/Year							
	Lac de Guiers	Lac R' Kiz	Aftout– es-Sahel[14]	Diama Reservoir	Senegal R. Estuary	Manantali Reservoir	Floodplain	TOTAL
Today	2,250	------	2,286	4,500	1,150	3,000	3,300-21,750	16,486-34,936

Source: DeGeorges (2006)

Given artificial flooding has been minimal, one would tend to lean to the low side estimate.

In 1992, a rural peasant farmers' association issued a manifesto which asked the administrative authorities, in cooperation with them, to regulate the artificial flood in such a way as to favor flood-recession farming and the reproduction of "*River fish*," and to evolve a land and development policy that gave priority, first to the present and future needs of River inhabitants, then to the present and future needs of the inhabitants of the rest of Senegal, and which took into account all possibilities for developing the land, not just irrigation. They received no reply (Adams, 2000d).

Impact of Senegal River Dams Forests

The Senegal River's Manantali reservoir destroyed 120 km^2 (12,000 ha) of forest within the inundation zone (Bosshard, 1999). The GFCC environmental assessment predicted more than 3 times this amount of forest being lost; about 7 km^2 (700 ha) of productive fringe forest along the Bafing River and 429 km^2 (42,900 ha) of less productive open forest would be permanently lost from inundation behind the Manantali Dam (GFCC, 1980b). The downstream impact from the Manantali from reduced flooding was projected to result in a loss of 76 km^2 (7,600 ha) of the remaining 379 km^2 (37,900 ha) of occasionally flooded *gonakié* forests and 10 km^2 (1,000 ha) of yearly flooded *gonakié* forests (GFCC, 1980e). *Gonakié* forests are composed almost exclusively of *Acacia nilotica* and are commercially valuable with a production rate of 1.43 m^3/ha/year (20 cubic feet/acre/year) serving as firewood, charcoal and food (e.g., seed pods and seedlings) for livestock and wildlife, among others (GFCC, 1980e).

Invasive Plants Behind Reservoirs On The Senegal River

Salvinia spp., Typha spp., Pistia spp. have all been problems. Biocontrol and water management helped control the *Pistia spp.* Water hyacinth (*Eichhornia crassipes*), the world's worst water weed is being sold as an ornamental at plant nurseries in the cities of Saint Louis and Dakar. If plants were somehow transferred to the river upstream of the Diama Dam, which is only 20 km upstream of Saint Louis, a new ecological disaster would emerge (Kloff, 2002). Fishing in the Diama reservoir is seriously hampered by the dense stands of *Typha spp.*, and by the floating invasives, *Pistia stratiotes* and (since 1999) *Salvinia molesta* that are blocking the channels (Hamerlynck, *et al.*, 2000). In addition, the 16,000 ha Djoudj National Bird Sanctuary and Diawling National Park across the river in Mauritania have both been threatened by invasive plants as noted above, in addition to, *Salvinia molesta*, though biological control using a weevil *Cyrtobagus salviniae* is helping to control this species. *Salvinia* "*forms a substrate for other*

[14] It was predicted that 5,000 tons of fish would be caught in the Aftout-es-Sahel after inundating 35,000 ha, but only 16,000 ha were inundated, meaning a yield of 2,286 tons.

invasive weeds, exhausts the river's oxygen and increases the habitat for disease-bearing snails and mosquitoes" (UNEP-WCMC, 2002).

Impacts on Nutrition from Dams & Irrigation on the Senegal River

The impacts of dams on nutrition in the following tables assumed that the rate of conversion of land to irrigation continues at the projected rates of conversion and that an artificial flood continues for 15 years. The importance of traditional production systems:

- Recession/*Waalo* Farming
- *Dieri/Jeeri* Farming (Rainfed)
- Herding
- Freshwater/Saltwater Fisheries

in 1980 prior to dam construction cannot be denied; making up 75% of the caloric intake and 92% of the protein intake within the Senegal River Basin (Table 5).

Table 5: Summary of projected, available amounts of nutrition from agricultural products on an annual basis with implementation of the proposed plans of development in the Senegal River Basin

	---1980---				---2000---				---2028---			
Sources of Total	**Calories $x10^7$**	**% of Total**	**Protein Grams $x 10^7$**	**% of Total**	**Calories $x10^7$**	**% of Total**	**Protein Grams $x 10^7$**	**% of Total**	**Calories $x10^7$**	**% of Total**	**Protein Grams $x 10^7$**	**% of Total**
Recession Farming	15,354	16	440	7	14,458	6	433	4	6,958	1	203	1
Dieri Farming	13,600	14	400	7	6,800	3	200	2	-	-	-	-
OMVS Irrigated Perimeters	23,000	24	450	8	182,590	72	4,576	43	395,700	85	9,837	57
Livestock	40,084	41	3,718	64	43,166	17	4,032	38	47,250	10	4,469	26
Riverine Fisheries	3,300	3	550	10	2,500	1	430	4	2,000	0	330	2
Saltwater Fisheries	1,400	1	240	4	5,320	2	912	13	14,000	3	2,400	14
Total	96,738	100	5,808	100	254,834	100	10,583	100	465,908	100	17,239	100

1) Because of rounding-off of numbers, percentages do not always add up to 100
2) Livestock includes cattle, sheep, goats and to a lesser degree pigs and fowl. It should be understood that under the present subsistence economy, livestock is not consumed to the degree that may be possible under a cash economy
3) By 2000 it was projected that sorghum and rice would become the two most important sources of calories from the irrigated perimeters
4) Dieri Farming – rainfed agriculture

Source: GFCC (1980a)

Actual consumption of cattle, for cultural reasons may have been much less than shown, but was projected to increase in importance as the Basin entered into a cash economy. One could also project, that if traditional food production systems were wiped out – as has happened – without replacing them with production from the planned irrigation, there could be an increase in livestock consumption as people enter into a survival mode or sale of livestock to obtain money to buy food that could no longer be produced. Of course wiping out the dry season forage habitat from reduced flooding without replacing it with high value forage as projected from the irrigated perimeters could also have resulted in a drastic decline in livestock as a nutritional or income source.

On the other hand, if in fact livestock was not consumed to the degree applied in the analysis, then the other traditional systems would become that much more nutritionally important if irrigation would not take off.

Even with the projected increase in irrigation offsetting the loss of these traditional production systems, caloric deficiencies in the Senegal River Basin were projected to become a problem by 2028 during peak development of the irrigated perimeters (Table 6). Due to the exponentially expanding human population, food demand by 2028 would exceed the linear growth of agricultural production as projected. It was projected the quality of the diet as measured by protein intake would remain adequate while deficiencies in the quantity of food consumed, as measured by caloric intake, would return to deficit levels. This deficiency was evident even without stratification of the populace by age groups, even though caloric deficiencies are more common in younger age groups.

Table 6: Summary of projected, available caloric and protein intakes for the population of the Senegal River Basin on an annual basis with implementation of the proposed plans for development

	1980	2000	2028
Population	1,649,500	2,901,100	6,274,500
Calories			
Total Available ($x10^7$)	96,738	254,834	465,908
Total Desirable[1] ($x10^7$)	138,476	243,547	526,744
Deficit (-)/Gain (+) ($x10^7$)	-41,738	+11,287	-60,836
Daily Per Capita Availability	1,607	>/= 2,300	2,034
Protein (Grams)			
Total Available ($x10^7$)	5,808	10,583	17,239
Total Desirable[2] ($x10^7$)	3,974	6,989	15,115
Deficit (-)/Gain (+) ($x10^7$)	+1,834	+3,594	+2,124
Daily Per Capita Availability	>/= 66	>/= 66	>/= 66

1) Assume Minimum value of 2,300 calories per capita per day for projected Basin populations
2) Assume average value of 66 grams of protein per capita per day for projected Basin populations.
3) Human population growth rate projected at 2.3% per annum
4) By 2028 rice and wheat would have to be imported into the Basin
5) Key assumptions are that a) Programmed levels of agriculture proceed at scheduled rate of implementation, b) The annual crop yields assume proper management of irrigated perimeters, c) Prior to export out of basin, local dietary needs would be met first.
6) Source: GFCC (1980a)

It was projected that caloric deficiencies (undernourishment) may ultimately result in protein malnourishment even though adequate supplies of protein might be consumed. This results from proteins being used as an energy source in place of much needed calories. Proteins are lost as building blocks for growth, repair and preservation of the body and bodily functions.

What actually happened is that the traditional systems have been virtually wiped out, and irrigation has failed to come anywhere near the projected 255,000 ha. The proposed artificial flood as of 1999 had not taken place to the degree planned meaning that recession agriculture and riverine/estuarine floodplain fisheries are minimal. So far only about only about 100,000 ha have been brought under irrigation, with only about 2,000 ha being added per year (Bosshard, 1999). Some say about 50% of the irrigation fields have been lost to soil salinization in the basin (GEF, 2002). As noted, the dams and dikes have reduced traditional grazing lands from 80,000 ha to 4,000 ha in the Valley (GEF, 2002).

Even if artificial flooding could bring 50,000 ha/year into recession agriculture production without going into a detailed analysis, it can be seen that there would be an immediate food crisis both with regard to caloric and protein intake, both falling into deficit categories. It must be presumed that the deficit in the near future can only be mitigated by:

1) Out Migration
2) Food Aid and/or

3) Remittances sent from family living in Dakar, or overseas.

Out migration from the Senegal River Basin by males in search of employment has been a factor since the 1940s, peaking during the drought of the 1970s because of a failing economy and desertification (GFCC, 1980a).

The GFCC environmental assessment (1980a) went on to say that if the population continued to grow as expected to over 6 million people in the river basin, and yet agricultural production remained at 1980 levels, the daily per capita caloric intake rate could fall to as low as 424 calories/person/day and protein as low as 26 grams/person/day. This would mean severe under- and malnutrition of the basin's inhabitants and an increased susceptibility to disease. From the failed irrigation schemes, and the destruction of traditional production system, one would have to assume by the late 1980s or at the latest early 1990s a nutritional crisis would exist unless mitigation was successful and/or remittances from family working elsewhere helped provide purchasing power to buy imported foods.

The switch from local grain to rice production and the reduction of fish consumption also have negative impacts on the diet of the local population. A study financed by USAID in 1994 of villagers in Senegal and Mauritania determined that their health has deteriorated. They are convinced that before the construction of the dams, the production of traditional food recession crops provided a more varied and healthier diet. The local population insists that it is because of their present diet, made up primarily of rice that they are weaker and have more health problems than before. Rice consumption is not only a consequence of the new dam, but also seems to have become a cultural preference in the Senegal Valley (Bosshard, 1999).

Other Health Related Issues

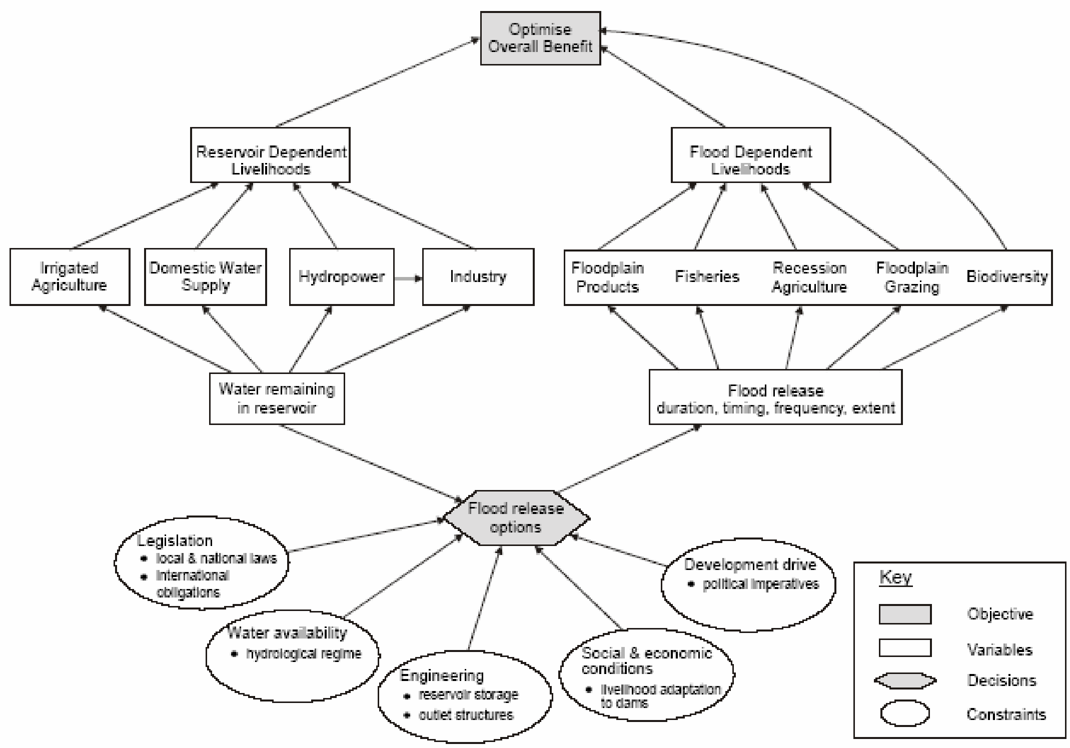
When the Diama and Manantali Dams were filled an epidemic of Rift Valley Fever (mosquito vectors) occurred, schistosomiasis (aquatic snail vector) prevalence rates reached record levels and riverside inhabitants experienced diarrheal disease, malnutrition and malaria, despite experiences with transmission of these diseases from earlier African dams (WCD, 2000). "*The dramatic increase in incidences of malaria and schistosomiasis in the Valley since the Manantali and the downstream Diama Dams were built, now claim 8,000 lives a year. The huge Senegal Sugar Co. near the Diama Dam in the lower valley is the focus of the worst bilharzia (Schistosomiasis) epidemic ever seen in Africa. More than 50,000 plantation workers are infected. In 1986, before the Diama Dam came into operation, there were no cases of bilharzia*" (Sevunts, 2001). In the past, seasonal fluctuations in flows and salinity helped keep the disease-bearing snails of schistosomiasis from taking hold (Pottinger, 1997). On the positive side, the Manantali Dam has eradicated River Blindness - Onchocerciasis, around the inundation zone and reduced the incidence downstream (McCully, 2001).

Planning & Mitigation

Mitigation is easier said than done. The problem is often the lack of political will to link technical planning into the political machinery of decision-making. Technical pre-dam planning, through multi-million dollar multi-disciplinary environmental assessments, was undertaken on the Senegal River, but misused or bypassed. We know what the problems are, and how to solve them, but the political will must be there. The basis of post-dam planning might be considered the new science of "Restoration Ecology," with a major goal of returning floodplains and estuaries, modified by dams and other hydrological structures, to their traditional ecological and production roles (Adams, 2003 *In:* Adams & Mulligan, 2003).

The most significant impact of most dams in Africa has been on the downstream floodplain ecosystems. As a result, "*The Sahelian Wetlands Expert Group*" (SAWEG) has been formed linked to the IUCN. SAWEG is a network of floodplain specialists working in the Sahelian region of West Africa. SAWEG currently includes around 100 members (SAWEG, 2001). The gains and losses from controlled flooding and the tradeoffs from various uses can easily be modeled (Figure 5) and have been, such as in the Senegal and Gambia River Basin environmental assessments. Political will often is the determining factor and tradeoffs of, for instance, hard currency from hydropower for governments, versus harder to quantify let alone see economic benefits to governments from maintaining these traditional production systems.

Certainly if one factors in the cost to human lives and society, the benefits of this mitigation greatly outweigh the costs.



Source: Acreman, Farquharson, McCartney, Sullivan, Campbell, Hodgson, Morton, Smith, Birley, Knott, Lazenby, Wingfield & Barbier (2000)

Figure 5: Flow chart depicting competing water uses that must be modeled against gains from controlled flooding

Monitoring

Once dams, development schemes (e.g., irrigation) and mitigation (e.g., artificial flooding) are in place monitoring to allow adaptive management and modification of management interventions must take place to allow impacted communities to mitigate unanticipated adverse impacts or take advantage of unanticipated positive impacts, ecologically, economically and socially.

Conclusion

It can be argued that by the time dam construction really took off in Senegal, there should have been enough knowledge by Western dam builders, who moved into Sub-Saharan Africa, to understand the environmental and social consequences of placing dams on rivers and what mitigative actions would be needed. Even if this was not the case, the detailed environmental analyses by GFCC on the Senegal River laid open the suppurating wounds that would occur if mitigation was not undertaken. Multi-disciplinary teams of hydrologists, modellers, engineers, public health doctors, wildlife and fishery biologists, agronomists and anthropologists/sociologists were employed. The consequences of building these dams were literally examined under a microscope. The environmental studies fill volumes of reports. Hydrological modelling was undertaken; gains and losses of traditional versus irrigated food sources were estimated. Plans existed for artificial floods as a major source of mitigation downstream. With few exceptions, across Sub-Saharan Africa, regardless of the dam, one can see similar consequences from the loss of downstream flooding and the displacement of people.

Major constraints to irrigation were not highlighted as strongly as they should have been, such as saline groundwater, soil salinization, diseases and the cost/ha of irrigation. Nutritional projections showed irrigation more than making up for the losses of traditional foodstuff. This laid the way for the construction of 2 dams on the Senegal, the displacement of 10-11,000 people behind the dam, adverse impacts on traditional production systems used by between 500-800,000 people below the dam, conflicts between traditional herders and farmers and nearly war between Mauritania and Senegal. Most of the people displaced by the dams today are worse off than before due to having both poorer quality and less land, and for many the psychological trauma from loss of their ancestral lands and the spiritual ties that go with them. Artificial floods in the Senegal River have been inadequate in both magnitude and duration to significantly impact the traditional floodplain production systems and thus the majority of people displaced downstream. With hydropower coming online, there is concern that the artificial floods will be less not more, maybe not at all. The rate of land going under irrigation is well behind that which was planned due to financial and technical constraints.

Will things be different in the future? Based upon the scandals coming out of the dams just finished, under construction or planned in Lesotho, it appears not (Bond, 2002, IRN, 2000, Hanlon & Pettifor, 2002, IRN, 2005, Lekhetho, 2005, Transparency International, 2005). Groups such as the International Rivers Network (IRN), a watchdog group and the World Commission on Dams (WCD) now based in UNEP (United Nations Environmental Program) in Nairobi, Kenya need to continue their vigilance and let the world know where dams and associated large-scale irrigation and hydropower schemes are both constructive and destructive. On the positive sides, pilot artificial flood programs in the Lake Chad Basin (Loth, 2004), in Cameroon, on the Kafue River, Zambia (DFID, 2002 & WWF Netherlands, 2002), the Zambezi Delta, Mozambique (Beilfuss, 2001, UTIP, 2002 & Zambezi Valley News, 2003) and associated with the Pongolapoort dam on the Phongolo River, South Africa (Acreman, *et al.,* 2000 & Beilfuss, 2001) offer great hope that the need to maintain traditional production systems, while bringing on new technologies is needed both to maintain the people and biodiversity of Sub-Saharan Africa. In this light, it is hoped that the Senegal River Basin will become a success story for the sake of its people and their biodiversity.

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