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THE SENEGAL RIVER BASIN MONITORING ACTIVITY: A PHASE ONE SYNTHESIS

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900 years ago, the Arab historian, Abu 'Ubayd 'Abd Allāh b. 'Abd al-'Aziz al Bakri (1981:82) noted in his Kitab al-masalik wa-'l-mamalik *a remarkable agricultural system in the Senegal valley based on flood-recession cultivation:*

> *The inhabitants sow their crops twice yearly, the first time in the moist earth (thara) during the season of the Nil [i.e., Senegal] flood, and later in the earth [that has preserved its humidity].*

That system, which has provisioned a population for at least a millennium, is no less remarkable today. Despite being under continuous cultivation for such a long period, the floodplain shows little or no evidence of secular degradation, of a progressive deterioration in its productive capacity (King 1990). The annual flood al[illegible] makes possible complementary exploitation of the plain by fishers and herders, it provides [illegible] woodland and pasture generation, and it supports biologically diverse wild and domesticated fauna and flora.

That system and the dense populations that depend on it are today under threat.

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Summary

1. Introduction

Until recently, the prevailing assumption among donors, governments, and the regional multistate river basin development organization was that after a transitional period the artificial flood from the Manantali Dam would be terminated, and the Senegal River waters would be managed uniquely for hydropower, irrigation, and navigation. This position was supported by cost-benefit analyses that compared the values of hydropower and flood-recession agriculture. These analyses that favored terminating the flood ignored the full range of costs: hydrologic, environmental, economic, social, and political. In 1987, the Senegal River Basin Monitoring Activity (SRBMA) began to explore the hypothesis that a permanent controlled release from Manantali would be justified by environmentally sustainable increases in production, income, and employment. In 1989, the Government of Senegal identified itself with a more holistic approach to river basin development than "power-irrigation-transport," and with a reconsideration of alternative management strategies for the dam.

2. Background

Along the left bank of the Senegal, most of which is in a low rainfall sahelian zone, 800,000 people support themselves with a diversity of smallholder productive activities. They fish, rear livestock, and cultivate rainfed millet, flood-recession sorghum, and irrigated rice; and wage-labor migrants send home remittances. This diversified system, which in the Middle Valley is well-adapted to the floodplain environment, depends on the annual flood, and is threatened by the Manantali and Diama Dams, which may seriously alter basin ecology. The challenge to development planners is to devise a strategy minimizing the adverse affects of the dams while maximizing their benefits through the maintenance and enhancement of existing production systems, the improvement and possible expansion of irrigation, and the generation of hydroelectric power.

3. The Problem

The argument to terminate the contribution to the flood from the Bafing assumes a competition for scarce water. The principal hydropower consultant for the basin claimed that a controlled release would entail an annual power loss of 3.591 x 10^9 FCFA (@ 21 FCFA/kwh), a loss more than twice the production value of 50,000 hectares in recession agriculture (1.7 x 10^9 FCFA/year @ 34,000 FCFA/ha). These figures, which were maintained by the consortium responsible for drafting the Left Bank Master Development Plan until as late as December 1989, may be flawed on two points: (1) an overestimation of the losses in power from flood-recession farming; and (2) an underestimation of the total economic returns from floodplain production.

4. Floodplain Agriculture: Recession and Irrigation.

Development initiatives in the basin remain narrowly focused on irrigation despite its historical record of rarely having met production or revenue

objectives. This weak performance is attributable to (usually unspecified) labor and capital requirements that are too burdensome for many households that allocate most of their capital to food purchases and most of their labor to a risk-minimizing diversified production repertory. A comparison of net returns to land, labor, and capital indicates that in years of adequate flood and rainfall higher net returns are achieved to the scarcer production factors--labor and capital--from recession farming than from irrigation. A sound development strategy must place irrigation in its proper perspective, as *one, and only one,* of the elements in a complex production system.

5. Intensification on the Floodplain

Advocates of expanding irrigation seek rates of intensification of 160 percent, approximately twice the rate currently achieved on irrigated perimeters. Yet on the floodplain, the calendric succession of fish, grain, and livestock production already generates a rate substantially greater than that hoped for on the perimeters.

5.1 Fisheries

The interaction of rivers with the lateral floodplain is critical for the reproduction of freshwater fish. In predrought years, the per hectare production of fish was approximately 70 kg, or about 35,000 FCFA @ 500 FCFA/kg. When that figure is compared with the value of flood-recession sorghum of 34,000 FCFA/ha, as estimated by the hydropower consultant, for a total of 69,000 FCFA, it indicates the importance of fishing both for household food consumption and for income.

5.2 Livestock and Pasture

The floodplain supports large herds of ruminant livestock during the dry season that browse trees, shrubs, grasses, and post-harvest grain stubble, and that manure the fields. Flood reduction is likely to lead to a sharp decline in the carrying capacity of the plain. One estimate of this decline yields a potential annual loss of 17,500 FCFA/ha.

6. Environmental Effects

6.1 Forestry

Acacia nilotica, the dominant woodland species in the Middle Valley, depends for its growth and reproduction on periodic flooding. The woodlands seem already to have suffered from the droughts of the 1970s and 1980s, and permanent reduction of the flood might prove devastating. The tree contributes to soil stabilization and provides fuelwood, charcoal, livestock browse, and termite-resistant wood for construction.

6.2 Domestic Water

Aquifer recharge depends on the flood. The shallow aquifer provides the Middle Valley and the extensive surrounding lands with ready access to water for household and livestock use and for irrigating small vegetable gardens, especially those managed by groups of women. A reduction of the flood will cause a lowering of water tables, and alternative methods will have to be introduced to assure continued access.

Boreholes tapping the deep aquifer may be the only solution, and these are costly to install and to operate. Even then, a sustained fall in groundwater levels will raise pumping costs, necessitate borehole rehabilitation and may lead to the inland movement of saline water in the delta.

7. Other Costs

7.1 Social and Political

By narrowing opportunities for a diversified production system, reduction of the flood may foster intense competition among individuals and groups for access to a reduced and homogenized resource base. This narrowing may also adversely affect the burdens of women, children, and the aged, who will remain in the valley while adult men seek remunerative employment elsewhere. As the rural exodus accelerates, the economic base of small towns in the region will deteriorate, since nongovernment employment in these urban centers is sustained largely by cash purchases from the rural sector.

7.2 Electricity

The hydrologic calculations of the engineering consultants to the regional river basin organization have informed the discussions on dam management, and they have fostered the notion of an incompatibility between power and controlled flooding. Their analysis asks what maximum amount of energy could have been produced continuously from 1904 to 1984 had there been a 50,000 hectare flood.[2] SRBMA's alternative calculations assume that in the very driest years, such as 1983-1984, there would be no artificial flood. The findings are that in 62 of 81 years there would have been sufficient water for both a 50,000 hectare flood and a guaranteed power output of 86 megawatts. Furthermore, in many of the 19 deficit years, there was sufficient water in the reservoir to have supported a controlled flood of the required volume for 50,000 hectares.[3]

8. Recommendations

On the basis of the above analysis, and on the separate SRBMA reports in hydrology, fisheries, agriculture, pedology, and socioeconomics, we propose a series of actions to be carried out under the overall coordination of the Government of Senegal's Cellule Après-Barrages, involving maximum participation of Senegalese individuals and organizations. These recommendations seek to assure integrated development that sustains the environment and generates income and employment along the left bank of the Senegal River Valley.

1. Introduction

1. SRBMA's work has been carried out in a changing policy environment reflected in the evolution of official Senegalese thinking about the artificial flood.[4] At the initiation of the research in 1987, the GOS identified itself with the OMVS position that the artificial flood was to be *transitional*, a temporary expedient to wean the floodplain population away from recession cultivation as new irrigated perimeters came on line. OMVS, the three member states, and the organizations lending for the Manantali and Diama dams agreed that, after the transition period, the dams would be operated to maximize hydropower generation and to raise the dry-season river flows to allow for riverine transport and more cost-efficient irrigation. This meant that the controlled September release from Manantali, adding to the unregulated flows from the Bakoye and Faleme rivers, would be terminated.

2. SRBMA began its studies testing an alternative hypothesis, that a controlled release from Manantali, lifting the Senegal's flow to flood levels, would be justified by environmentally sustainable increases in production, income, and employment. At that time, the World Bank accepted Sir Alexander Gibb & Partners' calculations that the artificial flood would engender an unacceptably high cost in forgone power (Andersen 1987). These calculations were based on assuring 100 percent power output in every single year from 1904 to 1984, despite the fact that no one advocating an artificial flood ever suggested that a release could be justified in such drought years as 1983-1984.

3. Although to this day OMVS holds to the position that the dams should eventually be operated without an artificial flood--indeed, OMVS maintains a lonely attachment to the notion of year-round barge transport from St. Louis to Kayes, despite the absence of commitment from any donor--Senegal (1989:16) first officially ventilated the possibility of an alternative strategy in January 1989. At that time, the Senegalese Minister of Plan and Cooperation, M. Djibo Ka, wrote:

> Monitoring the impact of the artificial flood is important because it will provide a sounder basis on which to decide whether to terminate it on the grounds that it unprofitably competes with hydropower generation, or to maintain it to some as yet undetermined time. Monitoring will also allow for appropriate agricultural interventions, involving both productive technology and plant breeding.

4. That suggestion apparently so impressed the consortium (GERSAR/CACG. et al. 1989:38) contracted to prepare a Master Plan for the Development of the Left (i.e., Senegalese) Bank of the Senegal River, that in their provisional report in December 1989 they made the possibility of maintaining an artificial flood the central issue to be resolved:

> *La culture de décrue constitue un moyen traditionnel de valorisation des sols du lit majeur du fleuve*

Sénégal. Les conditions pluviométriques des 15 dernières années ont cruellement mis en évidence les aléas d'une telle production vivrière en période de sécheresse persistante. La mise en service du barrage de Manantali permet de recréer artificiellement la crue, pour pallier une déficience de la crue naturelle. La réserve d'eau destinée à la crue artificielle est, ou sera, en concurrence avec d'autres utilisations de Manantali, jugées prioritaires car apportant une plus value significativement plus importante:

- *cultures intensives sur périmètres irrigués en maîtrise de l'eau,*
- *production hydro-électrique.*

Faut-il supprimer cette crue artificielle et à quel terme?

5. The conclusion of GERSAR/CACG. et al (1989), based on Gibb's 100 percent guaranteed power output model, was negative: the benefits of an artificial flood, in terms of increased agricultural production on the floodplain, are less than the costs, in terms of reduced hydropower.[5]

6. Only six months later, there has been a 180-degree turn, a complete reversal of position (GERSAR/CACG. et al. 1990:110). No longer seeking 100 percent guaranteed power output, the consortium now asserts that the costs of an artificial flood are less than its benefits. No longer restricting the comparison to power and irrigation on the one hand, and flood recession cultivation on the other, the consortium now accords value to other flood-dependent productive activities, such as livestock raising and fishing, and to environmental effects, such as reforestation.

7. With the shift in the official position of the GOS, from opposing to embracing permanency for the artificial flood and to seeing a complementarity among recession farming, irrigation, and hydropower, at least until land under irrigation reaches 100,000 ha, SRBMA now finds itself confirming rather than challenging the establishment stance. Instead, therefore, of providing detailed analyses of every element in the environmental and production system as we had initially anticipated doing, we shall consider these only briefly while concentrating on the one arena that remains problematic: comparing the cost and benefits of irrigation and recession agriculture.

8. SRBMA's findings provide strong support for Senegal's commitment to strengthening an environmentally sustainable, gender-sensitive, diversified production system along the left bank of the river: a system including rainfed farming of millet and other crops on sandy uplands during the brief rainy season, recession cultivation on the floodplain, irrigation, animal husbandry, and fisheries; a system that encourages growth of woodlands and pasture, assures safe and reliable water for domestic use, and facilitates the expansion of off-farm enterprises and employment.

9. In the first instance, the achievement of integrated development in the valley depends, as the June 1990

version of the Master Plan (hereafter indicated as PDRG, "Plan Directeur de la Rive Gauche") acknowledges, on the annual (or near-annual) flood. But it also depends on assuring the right mix of irrigation and flood recession farming. While a rapid expansion of irrigation has an obvious attraction, mainly because of its potential to increase yields per unit land, IDA's familiarity with irrigation--both in Senegal and more broadly in sub-Saharan Africa--suggests caution, a modest expansion carefully monitored. It is widely admitted, even by the most eager partisans of irrigation, that the Senegalese and African experience on perimeters of all sizes and with diverse systems of management has been disappointing: costs are much higher than anticipated; yields and rates of intensification are much lower;[6] farmers are reluctant or unable to invest capital and labor at recommended levels; farmer associations have proved to be unstable; pump downtime is excessive; fields need releveling sooner than expected; canals are often poorly maintained; etc., etc., etc. This poor performance, moreover, characterized a period when the State, through the Société d'Aménagement et d'Exploitation des Terres du Delta et du Fleuve Sénégal (SAED), prepared the land and provided necessary equipment and inputs at highly subsidized prices or even gratis. The New Agricultural Policy (1984) and the Structural Adjustment Program under which the Government of Senegal now operates call for a disengagement of the State from these actions, and a provisioning of equipment and inputs to farmers on irrigated schemes at prices that more nearly reflect their costs (Woodhouse and Ndiaye 1990).[7]

In the long run, the New Agricultural Policy expects farmers to assume the amortized costs of the perimeters as well.[8]

10. The fact that farmers seem eager to move to new perimeters while abandoning ones that are just a few years older--a process that has been labelled *irrigation itinérante*--should also signal caution. Clearly, irrigated schemes do best in their early years, once initial problems have been confronted and resolved. Lands are properly leveled; there has been no salinization of soils; equipment works; and both parcel holders and managers are enthusiastic and optimistic. This initially successful and subsequently deteriorated performance should influence the rate of bringing on new perimeters. Evaluations should be made not only in Years 1, 2, and 3, but subsequently as well, with appropriate monitoring mechanisms in place to identify precisely what works and what doesn't. Even though funding may be available to support a rapid increase in irrigated hectarage--figures as high as 5,000 ha/year of new land have been proposed--our findings strongly suggest a much slower, more experimental rate, predicated on careful land use analyses to assure not only that the perimeters are installed on technically appropriate lands, but also that they do not alienate the better flood-recession lands.

11. Even the alienation of poorer flood-recession lands is problematic. Households from castes without ownership rights to land may occupy the marginal areas of the floodplain (for example, higher parts of the basins that are flooded less often or for shorter durations), while members of the land-controlling castes hold the floodplain lands that are properly

inundated in most years. If the marginal lands are appropriated for irrigation, compensation should be paid not only to their jural holders (*joom ngesa*), but also to those who farm them as sharecroppers or under other forms of loan or tenancy. Equity considerations in the extension of irrigation must be considered on a site-specific basis, with appropriate prior socioeconomic as well as technical appraisals.

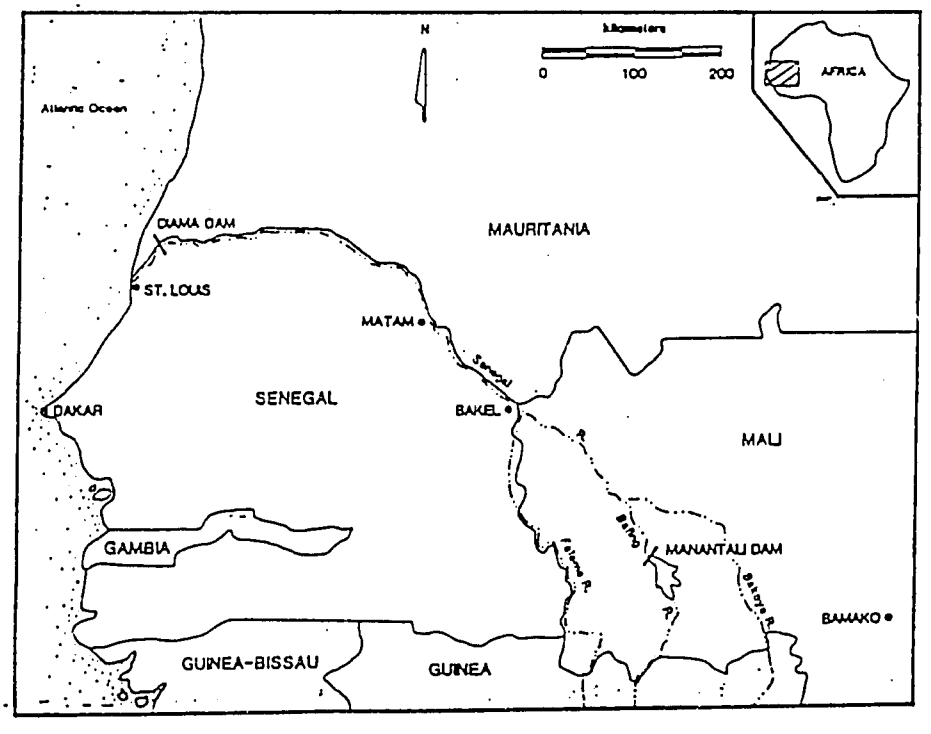
12. It is in the spirit of seeking to contribute to sound, equitable, and sustainable economic development that we offer this analysis of river basin management in the middle Senegal valley. Although our stance is sometimes critical, we appreciate that present policies have been elaborated on the basis of information available and with the intention of benefiting large numbers of persons. We would welcome at least as skeptical an examination of our work as we have given to that of others. We recognize too that without the excellent scientific inquiries carried out by hundreds of persons and many organizations, our exploration for alternatives would be severely hampered. Thus, we acknowledge with gratitude and admiration many of the studies that are cited herein, even where we may differ with their data, methodologies, analyses, or interpretations.

13. River basin development has the potential, if predicated on sound socioeconomic and environmental understandings, to benefit local, regional, and national economies substantially. Yet this potential is rarely achieved, and the huge sums invested in dams, dikes, irrigation systems, and hydropower installations typically provide disappointing and even negative rates of return, accelerate environmental degradation, and adversely affect the well-being of often densely settled riverine areas. In the following analysis focused on the middle Senegal valley, we offer suggestions on how better to realize the development potential of existing and planned river basin infrastructure.

2. Background

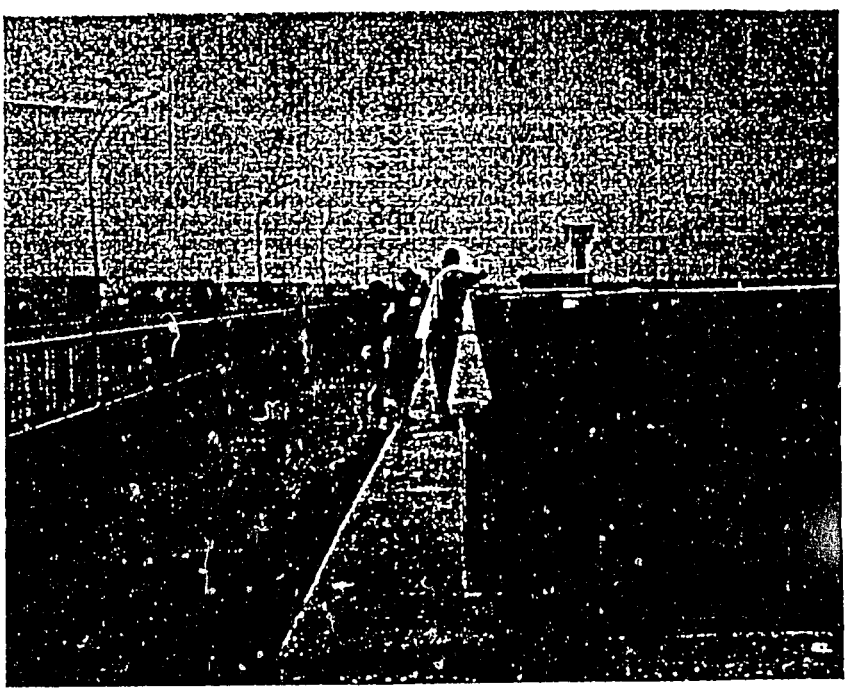
14. Following Guinea's withdrawal from the Organisation des Etats Riverain du Sénégal (OERS), in 1972 the remaining members, Senegal, Mauritania, and Mali, created the Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS). OMVS was charged with development of the Senegal basin, including the construction and operation of the Manantali high dam on the Bafing River in Mali, some 1,000 km upstream, and the Diama salt-intrusion barrage, 27 km from the mouth of the river in Senegal.

15. The Manantali dam, completed in 1988, is designed to control the downstream flow for (1) hydropower generation of 800 gigawatt-hours/year; (2) double-crop irrigation; and (3) year-round barge transportation from St. Louis on the Atlantic Ocean to Kayes in Mali.[9] Diama, completed in 1985, blocks the upstream migration of saline waters that previously travelled some 200 km during periods of low flow, and, after construction of a right bank dike, the dam will raise the level of fresh water to allow for more cost-efficient irrigation. By evening out the river flows--suppressing flood peaks and raising flows during the dry season--the dams will fundamentally affect basin ecology and production systems.



The Manantali Dam

16. Approximately 1,700,000 people occupied the Senegal basin in 1985, of whom 692,000 were in Senegal, 583,000 in Mali, and 425,000 in Mauritania. According to GERSAR/CACG. et al. (1990:21), the left bank figures for 1990 are 119,800 people in Bakel Department, 200,300 in Matam, 186,400 in Podor, 302,000 in Dagana, for a total of 808,500 people, 75 percent of them rural.[10] For the Departments of Matam and Podor, which contain the bulk of the lateral floodplain, 95 percent of the population is rural. More than 100,000 smallholder households downstream from the dam practice a highly complex set of production strategies. Despite generally low rainfall--much of the basin falls in the sahelian climatic zone--this dense population is possible because in average years the area sustains two harvests, one dependent on summer rains on coarse sandy upland soils (*jeeri*) and the other dependent on late summer floods on the alluvial plains (*waalo*)[11] composed of very fine, water-retaining vertisols. In addition, some of the floodplain is colonized by nutritious grasses, shrubs, and trees that supplement the graze provided by crop stubble; thus, in the dry season, large ruminant herds move from sandy upland pastures to the waalo, creating an animal population whose density echoes that of the humans. Until the drought of the 1970s and early 1980s, many fish were captured in the river and on the floodplain, adding to the consumptive inventory of the region.[12]



The Diama Dam

17. Large irrigation schemes exist in the delta and the lower valley, and in the middle valley small

village-owned and -managed irrigated perimeters have been developed since the mid-1970s, many with government assistance, adding a fifth element to the production array: (1) rainfed millet; (2) flood recession sorghum, maize, cowpeas; (3) irrigated rice (and, on a 7,500 ha scheme at Richard Toll, irrigated sugarcane); (4) livestock; and (5) fish.

18. This diversified production system is both constrained and supported by migration of young men who leave the area to search for wage labor and trading opportunities in urban centers and overseas. The area also supports a number of small commercial and administrative towns whose vitality depends in great part on the viability of the rural production system (Lericollais et al. 1990).

19. In their goal of insulating the region from the ravages of drought, the Diama and Manantali dams promise new prosperity. But, if the comparative evidence of African river basin development (Scudder 1988) is a reliable guide, the outcome is as likely to bring about an economic and environmental decline for those people most directly affected: the vast majority of the residents of the basin. Given the commitments that have been made by the three countries involved and by the international financial donor and lending community, is it possible to elaborate a management strategy for the river that mitigates the most severe negative consequences of the dams while still allowing reasonable utilization of the waters for hydropower and irrigation? We underestimate neither the task nor the economic and political constraints faced by the OMVS member states. The constituents for maximum hydropower generation and large-scale irrigation might not be numerous but they are powerful and often persuasive. Urban consumers demand cheaper and more reliable sources of energy. A *raison d'être* of large parastatal and private corporations is the development of huge tracts of land. European, North American, Japanese, and Korean civil engineering and construction firms seek to develop larger perimeters, build dams, and install power lines in the Third World, especially as such construction has virtually halted in their own countries. Financial institutions increasingly find integrated rural development an uncertain mechanism for assuring timely repayment of their loans.

20. The Manantali Dam is supposed to be managed with a controlled release of reservoir waters every September, in principle topping up the flows from the unregulated Faleme and Bakoye Rivers, and creating thereby an "artificial" flood.[13] This release is conceived of as transitional, an opportunity for the riverine populations to continue their complex production system while slowly being weaned away from traditional agriculture to year-round irrigation. SRBMA has explored the hypothesis that the net benefits to local, regional, and national economies are greater under the artificial flood than under a water regime that markedly limits the flood to maximize hydropower and irrigation. Our research effort has been informed by a desire to see the rural residents of the Senegal Valley become beneficiaries rather than victims of development, while their urban compatriots also profit from more reliable

electricity at potentially lower costs than currently paid.

21. In the remainder of this paper, we outline some of the findings of SRBMA and explore their relevance for the integrated development of the left bank of the Senegal valley. In the process we will compare them with some other recent proposals for river basin development,[14] and provide a set of recommendations for action.

3. The Problem

22. At the 21st OMVS Consultative Committee meeting in Bamako, 7-8 December 1989, the OMVS High Commissioner reiterated what was still the standard assumption that the artificial flood would be eliminated when it began to compete for scarce water. This would happen, the High Commissioner said, in the year 2000 when 95,000 ha in the valley would be under irrigation (USAID 1989). A supposed opposition between hydropower generation and flood recession cultivation was central to the thinking of Sir Alexander Gibb (1987), the OMVS' consultant on hydroelectric power, and was stated in the following way: the net benefit accruing from flood recession cropping of 34,000 FCFA/ha for a yield of 600 kg/ha is less than the cost of maintaining the artificial flood, based on losses in potential power due to these releases.

23. This hypothesis assumed that the power lost for each hectare flooded is greater than 34,000 FCFA; Gibb (1987) claimed that a controlled release will cause a loss of 171 GWh/year. At 21 FCFA/KWh, the lost electricity equals 3.591×10^9 FCFA, or more than twice the production value of 50,000 hectares in recession agriculture (1.7×10^9 FCFA). Although the 171 GWh would have been lost only in years such as 1982-1984, when it is hardly conceivable that anyone would have recommended an artificial flood, we will assume here that Gibb's calculations are correct. At the end of the paper, however, we will reexamine those calculations and suggest that they do not inevitably confirm Gibb's conclusion that an artificial flood is unduly costly in terms of forgone electricity.[15]

24. Our discussion incorporates a modified cost-benefit analysis. We recognize that conventional cost-benefit analysis has been widely and justifiably criticized for being too narrowly focused on measures that are easily quantified while ignoring others that prove unwieldy. For example, agricultural development--a shift from flood-recession agriculture to irrigation in this case--is often appraised uniquely for its expected direct impacts while its indirect and longer term impacts, such as environmental damage, are ignored or understated. In its review of twenty years' experience with rural development projects, the World Bank (1987) concluded that many of these projects failed to meet the rate of return projected at the appraisal stage precisely because the initial cost-benefit analysis excluded these other factors. The Bank felt that government and donor allocation of development resources could have been much improved had the indirect and longer term impact of projects been incorporated into the cost-benefit analyses. In the discussion below, we try to account for, and indeed calibrate, a broader spectrum of impacts than that with which development planners in the region have customarily dealt.

25. Cost-benefit analysis can produce misleading results for another reason as well. In the agricultural sector, different production regimes are often compared on the basis of crop yields per hectare without taking into account capital and labor constraints that may exist in a region. In promoting capital- and labor-intensive techniques to improve land

productivity, projects frequently overlook the fact that there are alternative and potentially more remunerative uses to which scarce labor and capital can be put. The agricultural options appropriate to such situations may not be those improving the productivity of the land as much as those improving the productivity of capital and labor. This observation is, of course, not unique to us, and has been elaborated in detail in a number of World Bank-sponsored publications (for example Cernea 1985; de Wilde 1967; Lele 1975).

4. Floodplain Agriculture: Recession and Irrigation[16]

26. Irrigated agriculture, on large schemes, on middle-sized schemes (*casiers intermédiaires*), and on small village schemes (*périmètres irrigués villageois* or PIVs), has been the major, indeed the only component of production in the Senegal River Valley that has received enduring government and donor attention in the years since independence. The World Bank, UNDP, and the French, Dutch, Italian, and American aid organizations, all have financed irrigation projects in the region. None has consistently met production or revenue objectives, or provided a favorable rate of return on investment, yet irrigation continues to be the centerpiece of development thinking in the area (although some donors have begun to evidence a disenchantment with the high costs and low returns from irrigation). Explanations for earlier failures focus either on technical considerations, implying that the solution is improved technology, or on the "mentality" of farmers who are reluctant to discipline themselves to the requirements of hydraulic agriculture. Little attention has been paid to the fact that, compared to other economic activities in the region--particularly flood-recession farming on the waalo and wage labor migration--a full commitment to irrigation is economically irrational. The comparative data demonstrate that irrigation is not a surer arena for farmer investment than flood-recession farming, though irrigation has provided some granary insurance against failed rainfed and recession harvests during droughts

Seeding a rice PIV

Sorghum harvest on waalo

27. The PDRG (GERSAR/CACG. et al. 1990) calls for an expansion of valley land in irrigation to reach 100,000 ha by 2015. At this point, we ignore the cost of bringing on new perimeters, and ask simply: are the yields from irrigation superior to those from flood-recession farming? All the documents agree that they are, and, indeed, our own field research confirms that yields per unit land actually in production are far

greater on the perimeters than they are in the waalo. Yet when net output is compared on the basis of all factors of production--production outlays and labor,[17] as well as land--the advantage of irrigation becomes questionable; when the amortized costs of developing the perimeters are included, that advantage evaporates.

28. The following analysis compares the performance of two production regimes--recession cultivation and PIVs--from the point of view of farmers in the middle Senegal valley. Later sections examine the broader social costs of limiting the flood. The quantitative analysis of floodplain sorghum production uses data from 43 parcels in Thiemping and Doumga Rindiaw, and that of irrigated rice production uses data from 60 parcels in Doumga Rindiaw and Thially.[18] In examining net returns to all factor inputs, the particular objectives and constraints vis-à-vis agricultural production of both the GOS and river basin households are discussed.

29. Senegal's promotion of irrigated agriculture in the 1970s was largely in response to deteriorating economic conditions in the country. According to USAID's January 1979 Country Development Strategy Statement:

> Senegal lacks the strong mineral resource base to form the foundation for an industrial economy. Its options for the present are limited to an agro-economy. Senegal enjoys a comparative advantage in groundnut production, but stagnating yields, the widely fluctuating world market price for groundnuts, the recent droughts, and the requirement to purchase large quantities of food grains on the open market have convinced policy makers that increased food self-sufficiency is a viable goal for the country and that, if this goal is ever to be reached by the end of the century, considerably more attention must be paid to the rural areas. (USAID 1979: 41)

The GOS turned to the Senegal river basin as the area with the greatest potential in terms of food production and embraced the development of irrigation as the preferred strategy because of its promise to improve land productivity substantially. This expectation is supported by the figures in Tables 1-4. The figures of net output per hectare for the two production regimes in the study villages clearly favor the development of irrigation. Whereas the value of sorghum production per hectare averages 28,717 FCFA/ha (at 100 FCFA/kg of sorghum) and 14,275 FCFA/ha (at 50 FCFA/kg), the equivalent value for rice is 209,313 FCFA/ha (at 136 FCFA/kg of decorticated rice) and 124,934 FCFA/ha (at 96 FCFA/kg).

Table 1
Irrigated Cultivation with Rice Valued at 136 FCFA/kg (SAED Market)[a]

Tenure	No. of Parcels	No. of Hectares	Gross output (kg)	Output (kg/ha)	Gross Value FCFA/ha at 136 FCFA/kg	Production Outlays		Net Output per ha at 136 FCFA/kg
						Land Use FCFA/ha at 136 FCFA/kg	Cash Inputs FCFA/ha	
Landowner	25	8.26	21,196	2,566.10	348,990	0	69,409	279,581
Lease	2	0.48	1,600	3,333.33	453,333	10,767	72,533	370,033
Loan	21	4.64	9,348	2,014.66	273,993	11,138	90,925	171,930
Sharecrop	12	2.98	5,261	1,765.44	240,099	112,999	80,236	46,864
TOTAL	60	16.36	37,405	2,286.37	310,946	24,058	77,575	209,313

[a] SAED buys paddy at 85 FCFA/kg. The conversion rate from paddy to decorticated rice is 62.5 percent. Thus the value of husked rice is estimated as 136 FCFA/kg. On the local market, which better reflects real costs than the SAED price, paddy sells for 60 FCFA/kg and husked rice for 96 FCFA/kg.

Table 2
Irrigated Cultivation with Rice Valued at 96 FCFA/kg (Local Market)[a]

Tenure	No. of Parcels	No. of Hectares	Gross output (kg)	Output (kg/ha)	Gross Value FCFA/ha at 96 FCFA/kg	Production Outlays		Net Output per ha at 96 FCFA/kg
						Land Use FCFA/ha at 96 FCFA/kg	Cash Inputs FCFA/ha	
Landowner	25	8.26	21,196	2,566.10	246,346	0	69,409	176,936
Lease	2	0.48	1,600	3,333.33	320,000	7,600	72,533	239,867
Loan	21	4.64	9,348	2,014.66	193,407	7,862	90,925	94,620
Sharecrop	12	2.98	5,261	1,765.44	169,482	79,764	80,236	9,482
TOTAL	60	16.36	37,405	2,286.37	219,491	16,982	77,575	124,934

[a] SAEL buys paddy at 85 FCFA/kg. The conversion rate from paddy to decorticated rice is 62.5 percent. Thus the value of husked rice is estimated as 136 FCFA/kg. On the local market, which better reflects real costs than the SAED price, paddy sells for 60 FCFA/kg and husked rice for 96 FCFA/kg.

Table 3
Recession Cultivation with Sorghum Valued at 100 FCFA/kg

Tenure	No. of Parcels	No. of Hectares	Gross output (kg)	Output (kg/ha)	Gross Value FCFA/ha at 100 FCFA/kg	Production Outlay		Net Output per ha at 100 FCFA/kg
						Land Use FCFA/ha at 100 FCFA/kg	Cash Inputs FCFA/ha	
Landowner	17	33.94	12,154	358.10	35,810	0	220	35,590
Lease	1	1.1	330	300.00	30,000	3,000	2,500	24,500
Loan	10	22.15	7,814	352.78	35,278	3,381	142	31,754
Sharecrop	15	40.08	13,497	336.75	33,675	12,268	72	21,335
TOTAL	43	97.27	33,795	347.43	34,743	5,859	167	28,717

Table 4
Recession Cultivation with Sorghum Valued at 50 FCFA/kg

Tenure	No. of Parcels	No. of Hectares	Gross output (kg)	Output (kg/ha)	Gross Value FCFA/ha at 50 FCFA/kg	Production Outlay		Net Output per ha at 50 FCFA/kg
						Land Use FCFA/ha at 50 FCFA/kg	Cash Inputs FCFA/ha	
Landowner	17	33.94	12,154	358.10	17,905	0	220	17,685
Lease	1	1.1	330	300.00	15,000	1,500	2,500	11,000
Loan	10	22.15	7,814	352.78	17,639	1,691	142	15,806
Sharecrop	15	40.08	13,497	336.75	16,838	6,134	72	10,631
TOTAL	43	97.27	33,795	347.43	17,372	2,929	167	14,275

30. The development of irrigation in the Senegal basin, in fact, did not keep pace with projected plans, nor did the performance of the perimeters meet expectations. The government ended by underwriting much of the costs for the perimeters. As of 1988, the GOS was incurring a net loss of 120 FCFA per kg of rice produced domestically, and the opportunity cost of growing the rice, given low world prices, was of a similar magnitude (Engelhard 1988: 22). The very high cost associated with the development of irrigation, moreover, came at a time when the government faced serious public sector deficits. Thus, the GOS found itself investing heavily in a capital-intensive agricultural scheme while trying to cope with serious budget constraints.

31. For farmers, irrigation was an attractive production alternative in the early 1970s because of the extended period of low precipitation and the poor or nonexistent floods at that time.

Farmers could not meet their household food requirements with rainfed and floodplain cultivation alone. But with the return of normal rainfall in the 1980s, irrigation lost some of its appeal. Farmers' apparent disaffection for irrigated rice -- notwithstanding its impressive per hectare yields relative to those for floodplain sorghum -- stems from the intensive use it makes of household revenues and labor, both scarce and, at the same time, very important resources in the production strategies of river basin households.

32. Protecting food security and minimizing risk are the chief aims of Middle Valley residents. Although household production of cereals is central to achieving this objective, off-farm generated income is increasingly relied upon to complete diets and cover periods of scarcity. Findings from Thiemping and Doumga Rindiaw indicate that expenditures for food items predominate in household budgets. In 1988-89, purchases of food constituted 78 percent of household expenditures in Doumga Rindiaw and 82 percent (6 percent for locally produced items and 76 percent for imported items) in Thiemping. Money for these expenditures came mainly from non-agricultural activities. In Doumga Rindiaw, about 67 percent of household revenues came from migrants' remittances, military and civil service pensions, and petty commerce. In Thiemping, the figure was almost 76 percent, and in Boyenadji Roumde, the third village in our sample,[19] nonagricultural activities contributed about 71 percent to household income. Clearly, household income is a resource vital to maintaining food security. Therefore, from the standpoint of the farmers, it makes good sense to give priority to that agricultural activity that is least intensive in the use of household revenues. The ratio of output to outlays shows that at both sets of prices floodplain sorghum brings higher returns to production expenditures than does irrigated rice production. Tables 5-8 demonstrate that the gross output-to-outlays ratio is much more attractive for waalo sorghum (1 to 5.61 and 1 to 5.77) than for irrigated rice (1 to 2.32 and 1 to 3.06).

Table 5
Irrigated Cultivation with Rice Valued at 136 FCFA/kg (SAED Market)

Tenure	No. of Parcels	No. of Hectares	Gross Output (kg/ha)	Net Output per ha at 136 FCFA/kg	Production Outlays FCFA/ha	Ratio of gross Output to Outlays	Labor days/ha	Net Labor Output FCFA/ day
Landowner	25	8.26	2,566.10	279,581	69,409	5.03	611	457
Lease	2	0.48	3,333.33	370,033	83,300	5.44	727	509
Loan	21	4.64	2,014.66	171,930	102,063	2.68	681	252
Sharecrop	12	2.98	1,765.44	46,864	193,235	1.24	501	94
TOTAL	60	16.36	2,286.37	209,313	101,633	3.06	614	341

Table 6
Irrigated Cultivation with Rice Valued at 96 FCFA/kg (Local Market)

Tenure	No. of Parcels	No. of Hectares	Gross Output (kg/ha)	Net Output per ha at 96 FCFA/kg	Production Outlays FCFA/ha	Ratio of gross Output to Outlays	Labor days/ha	Net Labor Output FCFA/day
Landowner	25	8.26	2,566.10	176,936	69,409	3.55	611	289
Lease	2	0.48	3,333.33	239,867	80,133	3.99	727	330
Loan	21	4.64	2,014.66	94,620	98,787	1.96	681	139
Sharecrop	12	2.98	1,765.44	9,482	160,000	1.06	501	19
TOTAL	60	16.36	2,286.37	124,934	94,557	2.32	614	203

Table 7
Recession Cultivation with Sorghum Valued at 100 FCFA/kg

Tenure	No. of Parcels	No. of Hectares	Gross Output (kg/ha)	Net Output per ha at 100 FCFA/kg	Production Outlays FCFA/ha	Ratio of Gross Output to Outlays	Labor days/ha	Net Labor Output FCFA/ day
Landowner	17	33.94	358.10	35,590	220	162.79	51	698
Lease	1	1.1	300.00	24,500	5,500	5.45	62	395
Loan	10	22.15	352.78	31,754	3,523	10.01	23	1,381
Sharecrop	15	40.08	336.75	21,335	12,340	2.73	54	395
TOTAL	43	97.27	347.43	28,717	6,026	5.77	46	624

Table 8
Recession Cultivation with Sorghum Valued at 50 FCFA/kg

Tenure	No. of Parcels	No. of Hectares	Gross Output (kg/ha)	Net Output per ha at 50 FCFA/kg	Production Outlays FCFA/ha	Ratio of Gross Output to Outlays	Labor days/ha	Net Labor Output FCFA/ day
Landowner	17	33.94	358.10	17,685	220	81.40	51	347
Lease	1	1.1	300.00	11,000	4,000	3.75	62	177
Loan	10	22.15	352.78	15,806	1,833	9.62	23	687
Sharecrop	15	40.08	336.75	10,631	6,206	2.71	54	197
TOTAL	43	97.27	347.43	14,275	3,097	5.61	46	310

33. The allocation of labor time over a diversified set of production activities, both on and off the farm, reflects the spatial and temporal strategies Senegal basin villagers have devised over many years to accommodate the risk inherent in activities that take place under harsh economic and environmental conditions. Floodplain agriculture is particularly suited to such a strategy as it yields relatively high net returns to labor and thereby contributes to household food stocks while freeing labor to engage in other productive activities, some of which, for example migration, are potentially very remunerative. Again, the tables indicate clearly the advantage floodplain sorghum maintains over irrigated rice. While irrigated rice farming requires labor inputs of 501 to 727 days per hectare, floodplain sorghum calls for inputs of 23 to 62 days per hectare. The average output per person day for sorghum in monetary terms is 629 FCFA/day (at 100 FCFA/kg of sorghum) and 313 FCFA/day (at 50 FCFA/kg). For rice, the equivalent figures are 341 FCFA/day (at 136 FCFA/kg of rice) and 203 FCFA/day (at 96 FCFA/kg).

34. For farmers, then, floodplain agriculture is an extremely important element in the production system both because of its relatively high returns to production expenditures and labor, and because it effectively minimizes risk. For the government, especially with the recent thrust to curb public expenditures, floodplain agiculture may also turn out to be attractive. Indeed, there is reason to believe that productivity levels on the floodplains could be increased substantially without requiring parallel and huge investments in research, infrastructure, and management.

35. The figures in Tables 1 through 8 are useful for comparing the performance of floodplain and irrigated agriculture, and they imply that the returns per unit land favor irrigation, while those for labor and production outlays favor recession cultivation. The net returns to factor inputs presented for rice production, however, may mask the disappointing experience of many farmers on village perimeters. More telling in this regard are the figures in Table 9 (also presented in Figure 1), which shows the distribution of area rice yields for the sample parcels. Although the average returns enabled farmers to recoup the costs of production, they did not always leave sufficient revenues to finance the next season's rice crop, and for many farmers with below-average yields, even production costs could not be met out of returns from the harvest. With rice at 96 FCFA/kg, only landowners and leaseholders netted enough to reinvest in irrigated rice production.

36. Such poor performance on the perimeters originates in their heavy production expenses and labor requirements and in customary land distribution and inheritance practices that gradually undermine producer group cohesiveness. Field research in the three study sites has demonstrated that households often prefer to allocate their limited cash and labor resources elsewhere, either to meet more immediate and pressing needs as in the case of household food purchases, or to achieve higher returns to these factor inputs, for example on the flood plains or from migration. To divert household revenues and labor to other activities or uses, most households are obliged to cut costs on the

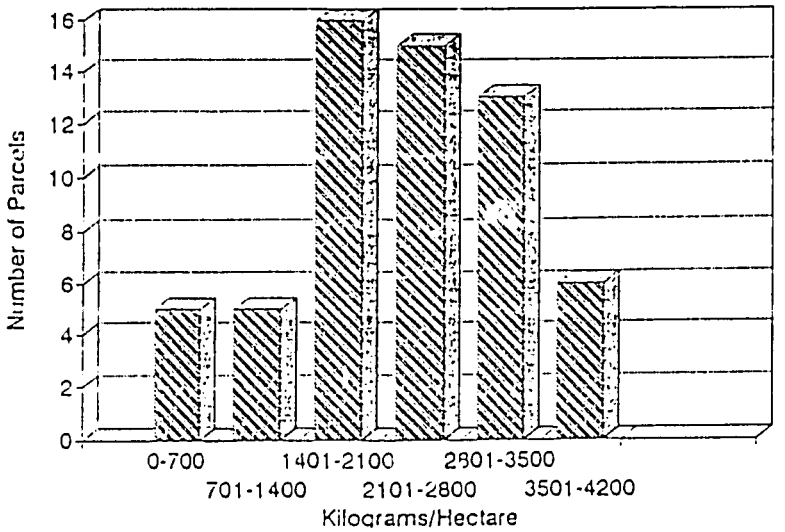
Distribution of Yields from Irrigated Rice Perimeters

Table 9

Range (kg/ha)	No. of Parcels
0 - 700	5
701 - 1400	5
1401 - 2100	16
2101 - 2800	15
2801 - 3500	13
3501 - 4200	6

Mean = 2,210
Std. Dev. = 926.38

Figure 1



perimeters and to employ women, children, and young adults on the perimeters. Farmers did not use phosphates in Doumga Rindiaw in 1988 and 1989, and the majority limited the use of urea to 50 kg per 0.30 ha plot, instead of applying the recommended dose of 100-150 kg. On Bossea I, the perimeter at Doumga Rindiaw, the data reveal that over 80 percent of labor in 1988 was undertaken by those between the ages of 5 and 24, thereby permitting older sons to migrate in search of wage labor. As a result of these practices, yields on the PIVs suffer.

37. In Doumga Rindiaw, the distribution of parcels has tended to accord with traditional practice. Particularly early on, when irrigated land was limited, de facto preference was given to elders, those from noble landholding castes, and men. These did not always coincide with those most in need of parcels and/or equipped with the requisite funds and labor resources to farm them. Moreover, the devolution of agricultural activities to relatives, sharecroppers, women, and children by those not interested or able to cultivate the PIVs has made it difficult to maintain the group cohesion and cooperation so critical to the proper functioning of perimeters.

38. Similarly, adherence to customary land inheritance procedures has meant that parcels of deceased plot holders are passed on to relatives, some of whom may be women, children, or migrants absent from the village. This seriously disrupts the unity of producer groups, as both women and children are excluded from the management meetings and absentee holders can contribute little to the day-to-day functioning of the perimeters.

39. It should also be noted that because households consume the bulk of what they produce, the funds for irrigated

production do not come directly from the sale of rice. Thus, at the beginning of each rice season farmers must tap other revenue sources. Some households are fortunate in that they have a relatively stable source of income from migrants' remittances. Other households, however, must rely on more precarious sources, such as loans or sale of livestock. In either case, because revenues are not always sufficient to cover the full costs of rice production, farmers must cut costs. Consequently, harvests are poor and the repayment of loans and growth of herds are made difficult. All too often, farmers end by abandoning their parcels, as in fact occurred in Doumga Rindiaw in 1988.

40. It has been claimed by advocates of rapidly expanded irrigation that the labor intensivity of the perimeters retards the rural-to-urban exodus. To date, this has not been the case. The returns from labor migration exceed those from local production activities for so many people that labor is often scarce in the Middle Valley. This scarcity is less critical in rainfed and in flood-recession agriculture than on the perimeters because the former are far less labor intensive. The paradox of the PIVs is that effective production on them requires both a good deal of liquid capital and a large and stable labor supply, but the relatively poor returns to both encourage labor to seek remunerative employment elsewhere.

41. The solution to these problems lies not in the abandonment of irrigation, but in placing it in proper perspective as one, and not necessarily the most important one, of a number of elements in a complex production system. The overall productivity of this system and returns to labor can be enhanced by the appropriate management of the Manantali Dam. But for people to make the necessary investments in sustainable agricultural production, they must be assured of continued and secure access to critical inputs, notably land, both irrigated and flood recession, and water.

5. Intensification on the Floodplain

42. A recurrent problem with irrigated production in the Senegal River Valley is its failure sustainably to achieve satisfactory rates of intensification. According to the PDRG (GERSAR/CACG. et al. 1990:96), the current annual rate of intensification for both PIVs and *aménagements sophistiqués* is only 0.83: that is, of the total surface developed in perimeters, only 83 percent is farmed in a given year.[20] The PDRG hopes to bring that figure up to 160 percent after six years of operation on a new or rehabilitated perimeter. Past performance suggests that such figures may be difficult both to attain and to sustain.

43. But such performance is already achieved on the floodplain, and without direct environmental, infrastructural, or external management cost. According to SRBMA studies, almost 100 percent of the cultivable plain that is flooded in any given year is in fact farmed. In November-December, after flood waters have receded, fields (waalo and falo) are planted. The harvest is three months later, in February-March. In addition, these recession fields also contribute to a "crop" of fish, and a "crop" of livestock and livestock produce. The calendric succession of floodplain exploitation--fish, grain, livestock--generates a rate of intensification that is not even imagined on the perimeters.

44. Let us examine each of these in turn, and attempt a rough calibration of their productive values.

5.1 Fisheries

45. The interaction between rivers and their lateral floodplains is critical for the reproduction of freshwater fish. That interaction is characterized by periodic flooding in which the main river channel and floodplain "side arms, oxbow lakes, marshes, swamps, pools, and the network of tributary streams" merge, and then separate as the flood waters withdraw (Ward and Stanford 1989:59-60). During the flood phase, nutrients on the plain surface dissolve in the water, and provide nourishment for freshly hatched and small fish. When the flooding is stopped or limited by storage reservoirs upstream from dams, there is invariably a resultant decline in the numbers of fish downstream. "In a 145-km reach of the Missouri river, flow regulation that resulted in a 67 percent loss of inundated floodplain area, was accompanied by a greater than 80 percent decrease in fish catch" (ibid.:60, citing Whitely and Campbell 1974).

46. The gentle slope of the middle Senegal valley--3 cm/km--facilitates the interaction between the river and the lateral plains, and the reproduction of most species of freshwater fish is adapted to the flood:

> *. . . la Vallée du fleuve Sénégal était une importante zone de reproduction de poissons d'eau douce (Tilapia, Silures). . . . Les inondations sont d'une grand importance pour le cycle vital de la plupart des poissons et des crustacés dans la vallée. Après l'inondation les plaines et la dépression inondées forment un habitat favorables à la reproduction*

et à la croissance pour les organismes aquatiques. Grâce à cela la biomasse de poissons et de crustacés augmente au cours de la période d'inondation.

Aucune grande inondation ne s'est pas produite ces dernières décennies à cause de la grande sécheresse, et la pêche a disparu presque totalement de la vallée (van Lavieren et van Wetten 1990:23).

Floodplain fishing -- "bunding and bailing"

47. While there is a good deal of recognition of the negative effects of a marked reduction in the annual flood on the reproduction of downstream fish populations, there has been little incorporation of that understanding in the cost-benefit calculations of the flood/no-flood scenarios. Recall Sir Alexander Gibb & Partners' statement that the costs of power forgone exceed the returns from flood-recession agriculture, estimated by Gibb as 34,000 FCFA/ha and by us as an average in 1988-1989 of between 14,275 and 28,717 FCFA/ha. What happens to that figure if returns from fishing are added to those from recession farming?

The catch

48. According to Dames & Moore (1989:6-31/2), termination of the flood "will lead to a loss of approximately 500,000 ha of floodplains in the Middle and Lower Valley. . . ." Reizer (1988) sees the loss at 400,000 ha on which fish reproduction depends. Gannett Fleming (1978) noted that there is an average fish production of 70 kg/ha/year. If this is true, then the per hectare value of fish (at 1990 prices of 500 FCFA/kg) is 35,000 FCFA, which added to Gibb's estimated returns from flood-recession farming yield 69,000 FCFA/ha. For the area as a whole, using Reizer's more conservative estimates, these figures indicate an annual yield of 28,000 metric tons. According to the USAID-sponsored "Senegal Natural Resources Management Assessment" (Grosenick et al. 1990:110), in the pre-dam period "the Senegal river fishery

produced 28,000 tons per year (some experts say 30,000 tons) and supported 10,000 full-time fishermen. In addition, it supported many part-time fishermen, providing supplemental protein for their families." This same document notes that the dams--appraised as contributing to insulating the region from drought--will cause an "artificial permanent drought" (ibid.).

49. Reizer (1988:264-267), using data from 1966-1968, years of "vaches grasses" when fish sold for 25-50 FCFA/kg, and from 1970-1972, years of "vaches maigres" when the price was 50-100 FCFA/kg, approximately one-tenth of current values, calculates the average annual income for fishers from both sales and autoconsumption as follows:

Table 10

Region	No. of Fishers	Total Revenue (FCFA)	Individual Revenue (FCFA)
Lower Delta	1,700	160,000,000	94,000
Upper Delta	2,200	260,000,000	120,000
Valley	6,200	560,000,000	90,000
Guiers	300	25,000,000	83,000

50. It is not the presence of the Manantali dam per se that will lead to such a drastic decline in downstream fish (in the way that North American dams, for example, have interfered with the upstream spawning migrations of Atlantic and Pacific salmon). Fish will disappear because the floodplains will no longer be accessible to them except in a few years. According to Robin Welcomme (1979:256), freshwater fisheries expert at FAO, managing Manantali with a permanent artificial flood will provide an environment for normal reproduction:

> The biology and ecology of the majority of fishes inhabiting floodplain rivers shows them to be extremely sensitive to any restriction of the floodplain and any modification of the flood cycle. . . . [An] important feature is the provision of sufficient water to produce a flood which will have the characteristics needed for the reproduction of fish species. This is a question of both quantity and timing which have to be based on an adequate knowledge of the biology of the fish species. Controlled releases of water have been tried in some systems, and on the Pongola

river a series of experimental floods have successfully filled the lagoons and induced breeding. . . .

51. Citing the work of Davies (1979), Ward and Stanford (1989:60) note that "many flood-dependent fish species resorb gonadal products in the absence of an annual flood and many will not spawn unless terrestrial vegetation is inundated. However, by managing releases from the dam to accommodate spawning migrations and terrestrial-aquatic interactions, it may be possible to sustain a fishery in the regulated riverine-floodplain system."

52. Reizer (1988:345, emphasis in the original), who has carried out ichthyological studies in the Senegal basin for more than 25 years, emphasizes the importance of the artificial flood for maintaining the productivity of the fishery:

> *La création de la crue artificielle minimale en août est, pour certaines espèces au moins, **une condition indispensable à leur survie.** La potentialité de reproduction sera affectée par la diminution de la surface de frayères disponsibles en année de forte hydraulicité, mais aussi par une augmentation au moins correspondante en année de faible hydraulicité. Sous la condition donc qu'une crue artificielle minimale (c'est-à-dire submergeant les seuils) soit créée en août, le bilan final sera positif.*

53. SRBMA's senior advisor on fisheries, Ian Dunn (1990), points out that the shallow nutrient-rich waters on the floodplain support a seasonal fishery with high production and consequently a high potential yield. The seasonality of the fishing is naturally controlled by problems of movement of the fishermen over the floodplain during the high water period. This restriction in fishing activity allows the young fish to reach a larger size before they are at risk of capture. The floodplain is of central importance, says Dunn, since only a small fraction of the total fish population derives from basic production of the main river channel itself. It is therefore theoretically possible to increase the overall offtake by controlling the discharge from the flood areas by means of sluices. In this way, the shallow water areas are maintained for longer periods with more fish growth.

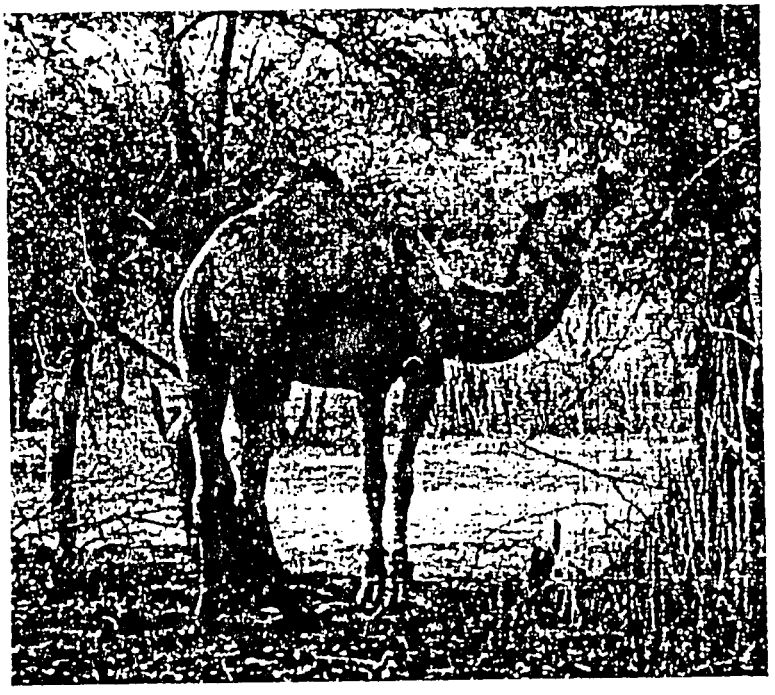
54. Although the drought and overfishing led to a depletion of fish stocks in the valley, we anticipate that the artificial flood will contribute to a near restoration of predrought populations on the inundated portions of the floodplain, since the rapidity with which fish mature in tropical waters usually leads to a fast recovery. Under normal conditions, the density of the population of adult spawners has small effect on the success of future recruitment until the number falls below a critical low level. The requirement to maintain target levels of electricity means that the lowest flows in the main channel will be 20 to 30 times greater than their historical minima. Such flows will provide a much improved refuge for the residual fish stocks at the end of each flood season. That is, increased dry season river flows will support larger stocks of fish, and the regular fall flooding will ensure their continued reproduction on the floodplain. Large-scale irrigation could, of course, adversely

affect this process of reproduction, especially if the waters become polluted by agricultural chemicals--herbicides, insecticides--running off the perimeters.

5.2 Livestock and Pasture

Cattle browsing cropped sorghum in waalo

55. The floodplains of the middle Senegal River valley constitute a critical dry season source of graze and browse for large herds of ruminant livestock in an area of sahelian rainfall regimes.[21] In June, with the beginning of the rainy season, most of the animals are herded onto the sandy upland (jeeri) regions, extending from the valley to the Ferlo, where rains and range fires encourage fresh grass flushes and where surface waters, pools formed by rainfall, and boreholes ease the often arduous task of watering stock from dug wells. As the rainy season draws to a close, in September-October, the animals move to the thin belt of harvested millet fields, browsing the stubble and manuring the land. This, indeed, is the pattern of transhumant herding throughout the sahel, and by the beginning of the new year both the quantity and quality of forage



Camel browsing arboreal pasture

declines, and animals begin to draw down their own fat, sometimes losing up to 40 percent of their body weight before the summer rains return.

56. But the floodplains of the Senegal valley provide a third element, enabling the herds not only to survive but actually to prosper during much of the dry season. Following the *waalo* harvests in February-March, animals are moved onto the plains, where they browse the sorghum and maize stubble, the *Acacia nilotica*, and other trees and shrubs, and where they graze palatable grasses that colonize uncultivated areas of the plain. Although their coverage is limited to the *upper* valley region, Dames & Moore (1989:6-12/13) provide a description of forage that is suggestive for other parts of the valley:

> Floodplain ranges are important in the project area and are found along the Senegal River between Gande and Ambidedi, and along the Faleme and Karakoro Rivers. Because these environments are less risky than those further from the river there are high population densities of people and livestock, resulting in degradation of this resource in some areas. These areas naturally support perennial grasses such as *Andropogon pseudopricus* and *Schoenfeldia gracilia*, and important tree species such as *Acacia seyal, A. nilotica, Combretum glutinosum*, and *Boscia senegalensis*. Range degradation decreases with distance from the river indicating the importance of water to livestock production. . . . In a well-managed state floodplain range carrying capacities between 1.5 and 5 TLU/ha are feasible. . . .

57. L. Diarra (1988:17), who examined grass changes in the inner delta of the Niger in Mali, concluded:

> Inadequate rainfall during 1980-1986, *coupled with frequent flood deficits*, considerably changed the plant composition and biomass production on vetiveria and eragrostis grasslands in the Niger floodplain. . . . Thousands of hectares formerly under perennial cover were rendered unproductive by unpalatable annual grass species, *Leptadenia hastata* bushes and termite mounds. The stocking capacity of the grasslands decreased drastically as a result of the diminished grazing reserves (emphasis added).

58. Van Lavieren and van Wetten (1990:10), citing South Dakota State University (1982), state that the alluvial plains constitute excellent pasture, capable of supporting 0.8-1.07 Tropical Livestock Units/ha/yr at the beginning of the dry season and having an average year-round carrying capacity of 0.41-0.54 TLU/ha.[22] This is to be compared with carrying capacities of 0.23 TLU/ha/yr on sudano-sahelian pastures and of 0.11 to 0.05 TLU/ha/yr on sahelian pastures.

59. This allows for the following worst-case calculation. Assuming a total cessation of the flood,[23] the carrying capacity of the lateral plains would be reduced from ca. 0.5 to ca. 0.15 TLU/ha/yr (a generous estimate for rainfed sahelian pastures with clay soils), a drop of

approximately 70 percent. (On 400,000 hectares of floodplain, this results in a diminution of livestock from 200,000 to 60,000, or a decline of 0.35 TLU/ha.) Assuming 200 FCFA per kilogram of liveweight (a conservative figure to capture the value of meat, dairy produce, hides, manure,[24] and social functions), this converts to a per hectare loss of 17,500 FCFA. Putting it positively, each hectare of inundated floodplain used for grazing contributes a value of 17,500 FCFA to its gross productivity.

60. The average annual value of output per hectare of inundated floodplain from these three forms of production is thus 14,275 to 28,717 FCFA for recession cultivation of sorghum, 35,000 FCFA for fish, and 17,500 FCFA for livestock, totaling 66,775 to 81,200 FCFA.

6. Environmental Effects

6.1 Forestry

Gonakié woods

Charcoaling

61. Trees are exceptionally important to the environment, especially in resource-poor countries such as Senegal, and, given global climate concerns, also important worldwide. Northern industrial countries, whose consumption of fossil fuels is the major cause of rising CO_2 levels, should seek to protect Third World woodlands from destruction. The Senegal River Valley was a heavily wooded region for so modest a rainfall profile, and the principal element in these woodlands is the *Acacia nilotica ("gonakié")*. Deforestation has had two causes: overcutting, especially for fuelwood and charcoal making, and drought.

62. After successive years of deficient rainfall and low river levels that led to a decline in the soil humidity necessary to sustain the gonakie forests,[25] the tree has proved to be reasonably hardy, and the floods of 1986, 1988, and 1989 have led to a good deal of natural regeneration. A permanent termination of the Bafing flood at Manantali, however, would lead to rapid deforestation. "If seasonal inundation is no longer available then there will be no *Acacia nilotica*" (Grosenick et al. 1990:83). In addition to being the major source of fuelwood in the region, the tree supplies vast quantities of charcoal that is exported to urban areas like Dakar despite regulations prohibiting it. Sixty-three percent of Senegal's primary energy is provided by wood, and in rural areas that figure rises to 99 percent (ibid.:91). According to GERSAR/CACG. et al. (1989:22), fuelwood requirements for rural areas of Matam Department exceed production by 110,660 m^3/year. (The study optimistically projects a reduction in demand and an increase in production such that the annual shortfall is 66,161 m^3 in the year 2000 and only 1,444 m^3 by 2015. The data on which so optimistic a scenario is based are hardly persuasive.) The tree's dense water-and-termite-resistant wood is used in construction, the pods are browsed by livestock,[26] and both the pods and the bark contain tannin used in curing hides.

63. The major recent environmental analysis of the river basin estimates the annual productivity of a well-developed gonakie stand at 8.2 steres/hectare (van Lavieren et van Wetten 1990:24). The tree also contributes to soil stabilization on the floodplain. According to one specialist (Gritzner 1988:82),

> The significance of the loss of riverine forests has not been fully appreciated in the Sahel. Field observations along the Senegal River made in 1979 and 1980 indicate that rates of erosion along the river have dramatically increased as the flood-plain has been stripped of its protective vegetative cover, particularly the extensive stands of *Acacia nilotica* so important as a source of charcoal. . . . The rates of erosion on the flood-plains of the Senegal will almost certainly result in levels of sedimentation and salinization far in excess of those currently anticipated by agencies involved in the further development of the Senegal River Basin.[27]

64. Finally, the trees that are made possible by the periodic floods also steady

Tree stand in bottom of cuvette

the flow of flood water down the floodplain.[28]

65. Even if the dam is managed to allow for modest floods, or the flows from the uncontrolled Faleme and Bakoye rivers prove sufficient to inundate much of the plain in many years, the *A. nilotica* forests may still be at risk, because the upland areas they occupy are likely to be flooded only in peak years, and since, in the absence of contrary management strategy, the dam will be operated to reduce the peaks (as well as the troughs), flood waters may reach these higher grounds much more rarely than they do at present. We do not, of course, know the extent to which embanked irrigation perimeters will raise flood levels, and whether this will mitigate the effect of lower overall river flows on woodland regeneration.

6.2 Domestic Water

66. We have discussed the effects of ending the flood on recession agriculture, fisheries, livestock, and wood supplies. At this point we turn to the question of domestic water supplies: if the flood is reduced, how will villagers obtain water for domestic use?

Women's garden watered from shallow well

67. Our finding (Hollis 1990a and 1990b) that the shallow aquifer is recharged primarily by infiltration of flood waters is seconded by GERSAR/CACG. et al. (1988:14) in the Matam master plan, and by van Lavieren (1987?:38).[29] This surface aquifer is exploited by villages throughout the floodplain with shallow wells to draw water for human and animal consumption and, especially among village women, for hand irrigating garden crops. The reduced flood recharge may lead to a drying up of these wells, and force users either to travel considerable distances to draw water directly from the river and marigots, with attendant health and sanitation risks, or to have boreholes drilled to tap the deep aquifer. To provide several hundred thousand middle valley residents with new, safe, and reliable sources of potable water will be an extraordinarily costly undertaking, and one that has not been adequately considered in the documentation for the region.

68. It is difficult to specify the costs of drilling boreholes without hard information on depth.[30] In 1983-1988, one rural water supply project in Senegal (Horsfield 1988), funded by British Overseas Development Administration, drilled and equipped 18 boreholes, providing safe and reliable potable water for approximately 85,000 people, at a total cost of £6,107,000, or £340,000 per borehole. Each equipped borehole served approximately 4,700 people. If we estimate conservatively the need to provide new potable water supplies to 300,000 left bank villagers, 64 wells would have to be drilled at a total estimated cost of £19,200,000 (or approximately 9,590,400,000 FCFA). If these 300,000 villagers occupy 100,000 hectares of floodplain, the per hectare cost of providing safe, reliable drinking water, over the useful life of the well, is approximately 96,000 FCFA plus annual maintenance and operating costs.

69. Assuming a useful borehole life of 30 years, the simple average annual per hectare cost would be 3,200 FCFA.

70. Yet even tapping the deep aquifer may not be an enduring solution if, as GERSAR/CACG. et al. (1988:14) indicate, both the shallow and the deep aquifers are recharged by the flood: "*L'alimentation de tous ces aquifères se fait en général plutôt par les eaux d'inondation que par les pluies.*"[31]

71. In conclusion, it appears that if the Bafing flood is terminated, new and expensive means of provisioning residents of both the Senegal valley and broad adjacent areas of Senegal and Mauritania domestic water supplies will have to be found.

7. Other Costs

72. It is important not to fixate on the quantities presented in the above analysis, but to consider the implications of their direction. The cumulative weight of SRBMA's findings tips the cost-benefit analysis away from a decision to terminate the artificial flood toward a management policy that seeks to optimize the benefits of water control for the broadest range of constituents: electricity consumers, small-scale agricultural producers, irrigation farmers, herders, and fishers. It shifts the decision away from one that would increase the vulnerability of the downstream environment to one that predicates economic development on a sound and sustainable environmental base. And it raises substantial questions about the desirability of pursuing a rapid expansion of irrigated perimeters at the expense of flood-recession cultivation.

73. We could rest the argument here. But there are other relevant issues that at least should be considered, although only one of them lends itself to a quantitative analysis.

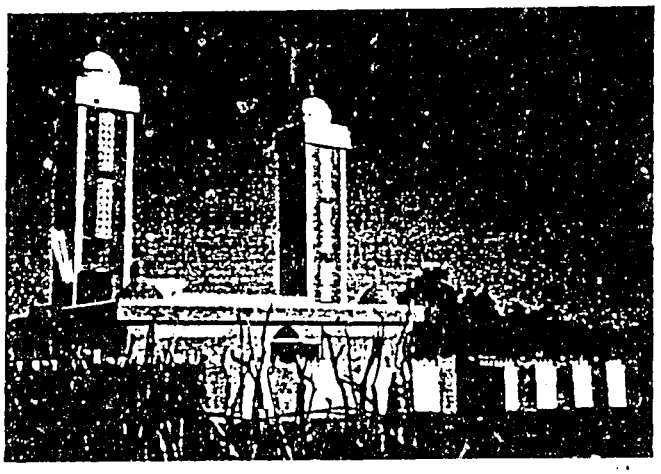
7.1 Social and Political

74. We have outlined some of the economic costs of an abrupt simplification of the complex and diversified production system that currently exists on the lateral floodplains of the middle Senegal valley. The progressive domination of irrigation over all other productive activities--recession cultivation, herding, fishing, forestry--will generate not only economic costs that exceed the anticipated gains, but also great social and political costs,[32] as ethnic and social segments that now have *complementary* access to resources (in the succession of fishing, farming, and herding), will find themselves in intense *competition* for a shrinking resource pool. Note that while the expansion of irrigation is very slow, currently at a net increase of less than 2000 ha/year on the left bank, the impacts of a cessation of the flood on all other components of the production system are profound and immediate.

75. In 1989 we witnessed the tragic consequences of such a competition along the right bank of the river, as Mauritanian elites in anticipation of a simplification of the production system acted violently to assume control over strategic resources, expropriate lands and forcibly expel local peoples (Horowitz 1989). In retrospect, these events should have been predicted. Although Senegal, unlike its neighbor to the north, is without a tradition of ideological apartheid, we are not at all sanguine that potentially violent conflict over land will not occur along the left bank too.

76. There will be a perhaps less spectacular but also profound impact of a reduction of the flood, particularly a suppression of the peak flood, on social and economic equity among the riverine population. The middle Senegal valley, homeland of the Haal Pulaar, is a highly stratified area, in which status is reflected in differential access to land. The dominant landowners control the best *waalo* lands, that is, those that most often receive a useful flood. Others are more likely to have holdings in the higher reaches of the basins that are flooded less frequently because they require greater river flows. If the peak flows are cut off, the the lands of farmers who are not

members of landholding castes will become flooded even less often than they are now, which will adversely affect their ability to produce even for their own consumption. The dam may thus intensify



Village mosque financed by migrant labor remittances

the existing stratification by worsening the economic position of those who do not have assured access to the better farmlands.

77. Equity relating to age and gender must also be considered in the anticipated shift from a diversified production system to one focused more exclusively on irrigation. As we have pointed out above, the capital costs of irrigation and the relatively poor returns from labor on irrigated fields encourage a heavy labor migration from the valley. This migration attracts young adult men to seek employment in urban areas of Senegal and overseas, and leaves behind children, the elderly, and women, who must then assume more of the burden of productive activity. Since irrigation is the most labor-demanding of all agricultural work, and since women, especially, will still have all their other domestic obligations, the leisure time available to them, and to children and old people, will become increasingly scarce. In addition, women have been discriminated against in the allocation of parcels on the perimeters. Moreover, older women may find that one of their off-farm employment opportunities, marketing locally caught fish in the villages, disappears as the reduced flood lowers fish yields.

78. A flood that is too small will lead not only to a progressive decline in household income and in the capacity of the environment to produce useful crops, but also to an accelerated exodus from the area. Europe has already shown a disinclination to welcome laborers from the Third World whose positions are increasingly filled by migrants from southern, central, and eastern Europe. After the integration of the European Economic Community in 1992, Europe may be effectively closed to Africans. Soninke and Pulaar men will find Dakar the almost exclusive target destination of their escape from the dam-driven, economically and environmentally degraded valley. How will Dakar receive them? What are the possibilities for expanding urban employment? What will be the effects of this migration on the urban quality of life, on housing, on crime, on violence? Are these not also "costs" to be factored into the Gibb equation?

79. Finally, there are likely to be adverse effects on off-farm employment in the region's small towns and secondary cities if the magnitude and duration of the flood proves inadequate to sustain a vigorous on-farm economy. In addition to housing government employees--whose number may be markedly reduced as part of the structural adjustment program--

these small urban centers provide employment to commercial and artisanal workers, whose livelihoods depend in large part on serving the needs of farmers, fishers, and herders.

7.2 Electricity *noch einmal:* Sir Alexander Gibb & Partners[33]

80. Management strategies for the Manantali Dam have been informed largely by the hydrological calculations of Sir Alexander Gibb & Partners. Using both their data and their estimates of the volume of water needed to generate a flood allowing cultivation of 50,000 ha ("Hydrogram A"), we asked the question: in how many years from 1904-1984 (the period included in Gibb's simulations) would there have been both enough water to allow a 50,000 ha flood *and* a guaranteed 86 megawatts of installed power? This question may be segmented into separate parts:

(1) In how many of these years would a 50,000+ ha flood have occurred with no additional release from Manantali?

Gibb (1987) presents the results of a simulation designed to follow water flows and reservoir levels while guaranteeing a minimum output of 86 megawatts. In 62 of the 81 years (76.5 percent), the average monthly flow at Bakel in August, September, or October is equal to or greater than 7.5 x 10^9 m^3, the volume required for a Hydrogram A flood. Therefore, in only 19 of 81 years (23.5 percent) would a controlled release have been necessary (although such a release might have helped flood a still larger area of the plain).

(2) How much release would have been required in those deficit years to bring the flood to a minimum 50,000 ha, and what would the effect of that release have been on hydropower generation?

The 19 deficit years are:

1907**	1942	1978
1913	1944	1979
1914	1972	1980
1921**	1973	1981
1940	1976	1982
1941*	1977	1983
		1984

In three of those years, just an additional 100 m^3/sec (**) or 200 m^3/sec (*) in any one month of the quarter would have created the target flood.[34]

81. Although the simulated peaks for these 19 deficit years were not high enough to assure a 50,000 cultivated hectare flood, the monthly data from the simulation shows that in many of these years the reservoir would have contained sufficient water to reach the requisite flow. In fact, analysis of the 86 megawatt simulation shows that, except for 1913, a year infamous in West African history for the severity of its drought, *for every other year from 1904 to 1977 the reservoir would have been filled to capacity before the end of October, and waters would have poured through the spillways of the dam through most of October and November.* Every drop spilled in excess of the amount required to generate 86 megawatts throughout the year could have, if required, been directed through a controlled release to augment the peak monthly flow during the critical flood period. In only 8 of 81 simulated years

(9.9 percent), did the reservoir not reach its full capacity: 1913, 1977, 1979-1984.

82. Gibb asks what is the amount of power that could have been produced 100 percent of the time had the reservoir been tapped to bring river flows to a 50,000 ha flood, and concluded that this condition would assure only 34 megawatts, an unacceptably low level. They therefore conclude that there is an irreconcilable conflict involved in guaranteeing both a flood and the desired power output of 86 megawatts.

83. This conclusion, uncritically repeated by Dames & Moore (1989), masks the fact that *in most of the 81 years 86+ megawatts would have been generated with no difficulty*. The disastrous drop to 34 megawatts is a consequence of attempting a flood in 1983-1984, the lowest rainfall years on record! In fact, another Gibb simulation (Phase 1 - Volume 1B, pp. B/10-B/13) shows that in 95.2 percent of the time (925 months out of 972), Manantali would have generated a minimum output of 74+ megawatts along with an annual controlled flood of 50,000 ha. Power dropped below that level in only 47 months (4.8 percent), and 37 of these months occurred during the record drought of 1980-1984.

84. The most recent version of the PDRG (GERSAR/CACG. et al. 1990:57) acknowledges the untenability of requiring a 100 percent guaranteed output in all years:

> *la forte discordance introduite dans la série hydrologique de référence (1904-1984) par les récentes années sèches fait qu'un critère de réussite fixé à 100 percent pour l'obtention d'un objectif (débit régularisé, crue artificielle ou production d'énergie hydro-électrique) conduirait à* pénaliser *l'ensemble des projets. Pour cette raison, les objectifs ont été calés sur un taux de garantie de 95 percent (5 années sur 100 d'échec). Ce préalable fixé, l'utilisation du stock de Manantali se pose en termes de* concurrence *comme déjà décrit dans ce rapport.*
>
> *Prioritairement:*
>
> *- entre la crue artificielle et la production d'énergie*
> *- entre la crue artificielle et l'irrigation*
>
> *Secondairement:*
>
> *- entre la production hydro-électrique et l'irrigation, de façon temporaire et lorsque l'irrigation aura atteint un stade de développement proche du seuil des 100,000 ha.*
>
> *En résumé, on peut dire que la présence d'une crue artificielle réduirait le débit régularisé garanti (à 95 percent) de plus de 60 percent (pour la plus petite des crues artificielles) et l'énergie hydro-électrique garantie (à 95 percent) de plus de 10 percent, ces taux de réduction augmentant notablement pour des crues artificielles plus conséquentes, de type B et C.*
>
> *En tout état de cause, il serait possible de fournir un débit régulé moyen garanti (à 95 percent) de 150 à 200 m^3/s pour des crues*

artificielles, respectivement, de type B et A. Ces débits sont jugés suffisants pour couvrir l'ensemble des besoins en eau dans la vallée pour une surface irriguée totale (rives gauche et droite) de 100,000 ha.

85. We are naturally pleased to find our concerns about the Gibb calculations of the effect of an artificial flood on potential hydropower shared by the consortium responsible for drafting the Left Bank Master Plan.

8. Recommendations[35]

86. The discussions leading to these recommendations are found in this synthesis report and in the sections of the final report concerning hydrology, fisheries, agriculture and soils, rural-urban linkages, and socioeconomics. In carrying out these recommendations, maximum involvement must be made of Senegalese institutions and individuals, including residents of the Senegal River Valley.

87. During Phase One of the Senegal River Basin Monitoring Activity (SRBMA-I) the following changes and new needs have begun to influence the development arena for the region:

- a financial crisis that led to the implementation of Senegal's New Agricultural Policy and structural adjustment program calling for a progressive disengagement of the State from direct involvement in agricultural operations (including ending State subsidies for agricultural inputs to farmers and ending the State's role in agricultural marketing);

- an increasing interest in the "private" sector in development;

- an increasing awareness of the need for environmental sustainability in development;

- a declining European receptivity to African migrant labor;

- ethnic conflict and violence in the region, resulting in, among other things, the expulsion of thousands of black

Africans from Mauritania and their settlement along the left bank of the river;

- an annual rate of population growth estimated at 2.6 percent;

- recent locust infestations and a 15-year period of drought and poor or absent river floods that decimated yields from rainfed and flood-recession cultivation; and

- the need for greater food security throughout the country.

The recommendations that emerge from Phase One of SRBMA's research are offered within the context of these events.

88. Support for a Sustainable Diversified Production System. We recommend that the dam be managed to support a diversified production system in which environmental sustainability and socioeconomic growth-with-equity are acknowledged as guiding principles. This implies that dam managers will release the volume of water from the Manantali reservoir that will maximize floodplain production and environmental sustainability consistent with the requirements of hydropower and irrigation. At present there are no turbines at Manantali, and water resources are adequate for the existing perimeters. At this time, therefore, it would clearly be premature to initiate a management strategy based on PDRG "scenario A," which limits the area of cultivable floodplain inundated to 50,000 hectares. Furthermore, as discussed in detail in SRBMA's hydrological reports (Hollis 1990a and 1990b), the current timing of Flood "A" is not optimal, since it comes after the peaks from the unregulated tributaries (see Paragraph 91).

89. Groundwater Recharge and the Availability of Groundwater for Irrigation.[36] A controlled flood should become a permanent feature of the water management of the valley also because the groundwater in the alluvial, surface, and deeper aquifers of the valley, and probably those over wide areas of northern Senegal, are recharged primarily by the infiltration of flood water through the floodplain. Wells drawing on these aquifers are critical for the supply of water to villages and livestock, and are used for watering of women-managed vegetable gardens. The water quality effects of enhanced groundwater recharge through the percolation of irrigation water should be monitored through the existing Groundwater Monitoring Network. While there is interest in using groundwater for irrigation, such schemes should not be implemented prior to a full understanding of their effects on water quality and availability. When groundwater-river relationships are better understood, consideration should be given to the joint use of surface and groundwater resources.

90. Monitoring, Evaluation, and Research. To make up for critical gaps in current understandings, we recommend the immediate establishment of an integrated Senegal River Basin monitoring, evaluation, and research activity, coordinated by the Cellule Après-Barrages. This means that CAB will require increased staffing in the social and environmental sciences and an expanded capacity for documentation and data management. Training programs for

Senegalese personnel should be instituted, either in-country or abroad as necessary, where essential skills are lacking.

91. Hydrology and Management of the Artificial Flood. While the synthesis report points to major socioeconomic and environmental lacunae in understanding Senegal Valley production systems, there are also fundamental shortcomings in our hydrological understandings, and these shortcomings render current attempts to manage the controlled releases from Manantali extremely problematic. The management rules for Manantali should aim at augmenting the natural flood from the uncontrolled portion of the upper catchment rather than endeavoring to follow artificial flood Hydrograph "A." This would have the effect of requiring less water; it would normally lengthen the growing season for flood-recession crops; and it would reduce the frequency of undesirable double-peaked hydrographs. The present real-time forecasting model developed for the river is inadequate to guide augmentation of natural flood flows because it gives only a two-to-three day forecast of flow at Bakel. A real-time hydrological forecasting model, incorporating both a rainfall/runoff component and a hydraulic component based on river levels, should be developed that will furnish two-to-three week forecasts of the flow at Bakel. To build such a model, links must be established with Guinea in order to obtain the necessary rainfall and flow data for the uppermost parts of the Senegal catchment. In addition, the feasibility of extending the existing METEOSAT-based telemetering of real-time climatological data should be investigated.

92. Flooding Mechanisms in Cuvettes.

(1) The blockage and restriction to the flow of water into cuvettes and along distributary channels should be investigated prior to implementation of a low-cost program of dredging and excavation at critical points. This program will assist both cuvette inundation and water supplies for irrigation. Plans for the construction and management of sluices where distributaries leave the main river should aim at the integrated management of water levels for the benefit of fishing, flood-recession cultivation, and irrigation.

(2) The complexity and variability of flow directions on the floodplain together with significant flows in some places requires that embankments not obstruct floodways. Locating irrigation schemes on higher and sandier lands within cuvettes will reduce the costs of embankments and lower the rise in flood levels. Flood-level rises are caused by a reduction in the storage capacity of the floodplain produced by embanking perimeters. The construction of temporary roads across distributary channels should be undertaken only where there will be no adverse effects downstream and where the entire structure will be fully removed before the ensuing flood season.

(3) Sufficient data exist to elaborate a physically based deterministic model simulating the actual processes of inundation of the floodplain from Bakel to Kaedi and probably to Richard Toll. The model will need to operate on a daily basis.

93. Effects of Irrigation on the Floodplain. It is critical that large

schemes *not* be designed so that their drainage into the existing marigots and then into the cuvettes will cause rapid salinization of the cuvette, groundwater, and eventually large parts of the perimeter itself. It is further recommended that any move to replace the bridges on the Matam-Ourossogui road with a continuous embankment be viewed with extreme caution. Such a replacement will seriously impede flood flows down the floodplain, and there is a danger that, during a large flood, floodwater will pass through the town of Matam which is lower than the crest of the embankment. On the scheme currently being erected near Boyenadji, it is recommended that the marigots be dredged so that drainage water can discharge via non-return flaps into the Diamel, and that an extensive floodway be left through the perimeter so that floodwater from the Dioulol, Navel, and Thiemping cuvette can pass through to the Diamel and beyond.

94. Hydrological Studies.

(1) Top Priority. A real time flow forecasting model with a forecast horizon of at least two weeks must be developed for Makana and Bakel.

(2) Very High Priority. There should be test releases of sustained base flows from Manantali to permit studies of the fate of the released water. Special attention will have to be given to water levels in the river between existing gauging stations, water levels in distributary channels and the current metering of rates of flow at critical points.

(3) High Priority. Stage boards should be established in each of the cuvettes selected for intensive study and at strategic locations along the distributaries and marigots. These boards should be read daily during the flood seasons, preferably by observers resident in local villages. The stage boards will have to be carefully leveled to yield elevations in m IGN.

(4) Medium Priority. Flow volumes into critical cuvettes and long important channels should be metered repeatedly during flood passage so that their movements can be calculated and relationships established between the slope of the water surface among stage boards and the discharge.

(5) Medium Priority. A new physically-based model of the hydrology of the valley needs to be developed and calibrated with the existing wealth of data for the river and the scanty but adequate data on water levels in distributaries and cuvettes, groundwater levels, and the extent of flooding. The new model will have to take into account the flooding and drainage processes for individual cuvettes; groundwater-surface water relationships; withdrawals of water, inculding irrigation, that are foreseen; and the return of drainage water to the river. The main aims of the model will be the determination of the water levels that will be attained in the dry season under different development scenarios and the extent of flooding during the release of the artificial, or augmented, flood from Manantali. There is sufficient data on the physical hydrology of the river and floodplain to begin this modeling work immediately, but new data will be needed for model testing and verification.

(6) High Priority. Monitoring of the OMVS/USAID Groundwater Network should be continued and the data entered into the existing data base.

(7) High Priority. A report should be prepared on the groundwater resources in the Middle Valley using the OMVS/USAID Groundwater Monitoring Project's database. The study should include consideration of the effects of changing the flood regime on groundwater in the wider region.

(8) Low Priority. There should be some investigation of the soil moisture in waalo lands emphasizing recharge/drainage relationships, the significance of rainfall amount and timing, and the processes of evaporation and transpiration.

(9) Medium Priority. While flows from the uncontrolled parts of the upper basin are reported to have exceeded Artificial Flood "A" in 52 of the 68 years from 1903-1971, there is some evidence that the recent drought years have significantly lowered the proportions of flow at Bakel that come from the Faleme and the Bakoye. A study of temporal trends in relationships between rainfall and runoff and between the relative contribution of each tributary is needed. The study should accompany the present investigation of the effects of different operating regimes at Manantali on the actual flow at Bakel.

(10) Low Priority. An overview should be prepared on sediment movement because little attention seems to have been given to its transport on the floodplain, and to sediment and nutrient deposition in Middle Valley cuvettes.

95. Remote Sensing and GIS. There is a lack of firm documentation on the relationship between the volume and duration of flood waters and the extent of area inundated. The various "hydrograms" proposed for management of the Manantali Dam are the products of simulations, and appear not to have been empirically verified, nor have claimed relationships between the area of cultivable floodplain inundated and the area actually under recession agriculture. Some of these issues could be resolved by a retrospective examination of satellite imagery, involving, for example, the participation of the Centre de Suivi Ecologique, combined with ground-truthing. We make the following recommendations:

(1) The existing work of mapping flood extent from SPOT imagery should be continued in 1990 and thereafter for at least five more years, and 1989 satellite images for the valley should be obtained and analyzed. The analyses should clearly distinguish areas flooded by the river from those flooded by rainfall and runoff.

(2) Consideration should be given to the analysis of LANDSAT scenes dating back to 1972 to allow fuller understandings of floodplain inundation and the relationships between flows and areas inundated. It would also be useful to distinquish areas flooded from those actually cultivated.

(3) A digital terrain model of the valley should be created using ARC-INFO. This will serve as a base both for the OMVS geographic information system and for the hydrological modeling proposed.

96. Dam Release Simulations. We recommend simulating the dam's releases of different sizes against the historical record to indicate what their effects would be on the following year's reservoir capacity.

97. Agronomic Research.

(1) Agronomic research to increase the productivity of land, labor, and capital in agriculture--especially to improve per hectare yields on flood-recession fields--is essential and might best be undertaken by the Institut Sénégalais de Recherche Agricole (ISRA), in collaboration with SAED. There is general agreement on the desirability of improved productivity on the floodplain, but few concrete efforts are being undertaken to achieve it. In the PDRG list of research themes to be carried out (GERSAR/CACG. et al. 1990:77), none deals with waalo agriculture. Yet there is considerable agreement among scientists that such research would have a high payoff:

> Despite the risks of crop loss. the cultivation of wetlands and floodlands tends to be more sustainable than most tropical rainfed farming because salts are washed away, and fertile silt is often deposited by floodwaters. . . . There would seem to be considerable scope for improving flood recession agriculture and for extending the area under such use. Floodplains and swamps can be made to drain faster by cutting drainage channels, thereby extending the growing season and improving security of harvest, and if the channels remain full, providing a source of irrigation water during dry periods" (Barrow 1987:192-193).

(2) GERSAR/CACG. et al. (1989:13) concede that waalo yields can be increased from 550 kg/ha in 1990 to 900 kg/ha in the year 2000, and to 1,000 kg/ha by 2015. Similarly, van Lavieren (1987?:20), noting how rarely irrigation in the Senegal Valley actually yields two harvests a year, and how it is possible to increase flood recession yields to 800-1000 kg/ha, wonders *"s'il faut appliquer ces changements agricoles rigoureux de façon absolue. Il semble opportun de reconsidérer l'importance de la culture dans le Walo, qui est adaptée au milieu naturel ainsi qu'aux traditions de la population."* It is interesting to note that prior to the great expansion of Senegal valley irrigation in the 1970s, there was a good deal of interest in improving both rainfed and flood-recession yields (Chevreau and Poulain 1972; Poulain et al. 1968; Sapin and Reynard 1968; and, more recently, Watt 1986). Some of the agronomic research activities to be undertaken include:

- plant genetics, to develop more stress-tolerant, pest-resistant, less-water-demanding varieties; and/or shorter cycle varieties that mature before the onset of the extremely hot dry season;

- fertilizer responsiveness, if a method can be developed for delivering fertilizers, given the fact that planting awaits the recession of surface waters;

- small-scale infrastructure to increase the efficiency of flood waters (e.g., sluices on the marigots, dikes);

- better integration of livestock on waalo fields; and

- cultivation techniques to increase the efficiency of labor, spacing, intercropping (for nitrogen fixation, shade).

98. Environmental Research. Environmental research and monitoring should also be undertaken, perhaps involving a consortium of Senegalese (for example, SAED, ISRA) and other organizations (such as Centre de Suivi Ecologique [CSE], ENDA, ORSTOM), again as coordinated by the Cellule Après-Barrages. For example, the PDRG (GERSAR/CACG. et al. 1990:126) speaks of the "necessity" for destocking animals in the Senegal valley, yet no evidence is presented to indicate that herd size so consistently exceeds carrying capacity that the productivity of the range is threatened. On the other hand, CSE has stated that no evidence exists to show that the region is being desertified. Appropriate monitoring would focus on soils, water, and trees. Monitoring tree growth is especially critical as different flood regimes are likely to affect the sustainable yield for fuelwood, construction, and forage.

99. Socioeconomic Monitoring and Research. Finally, and perhaps most importantly, a valley-wide monitoring of the socioeconomics of smallholder producer households should be undertaken, including considerations of land tenure, labor requirements, price policy for agricultural and for rural consumer products, and linkages between the countryside and small administrative and marketing centers. In close coordination with the CAB, the Institute for Development Anthropology will be developing an appropriate monitoring protocol during 1990-1991. The long-term implementation of that protocol, and the analysis of the findings, should be carried out by the various national and international organizations concerned.

100. Conclusion. If the record of the twentieth century is a reliable guide to the future, our analysis suggests a management strategy for the dam that allows for a release from Manantali in all but the very few years when in August and September both reservoir levels and river flows are too low. There is little reason why the Manantali dam cannot be operated to generate hydropower at desired levels, to allow for a reasonable level of irrigation in the valley, and to enhance downstream ecology, productivity, income, employment, and social justice.

Bibliography

al-Bakri, Abu 'Ubayd 'Abd Allah b. 'Abd al-'Aziz
1981 [Selections from] Kitab al-masalik wa-'l-mamalik. *In* N. Levtzion and J. F. P. Hopkins, Corpus of Early Arabic Sources for West African History. Cambridge: Cambridge University Press.

Andersen, Dennis
1987 Scope of tariff and project justification studies. Unpublished report prepared by the World Bank (WAPDR) for the OMVS.

Barrett, Scott
1989 On the Overgrazing Problem. LEEC Paper 89-07. London: International Institute for Environment and Development.

Barrow, Chris
1987 Water Resources and Agricultural Development in the Tropics. Essex: Longman.

Cernea, Michael M., ed.
1985 Putting People First: Sociological Variables in Rural Development. New York: Oxford University Press for the World Bank.

Chevreau, M., and M. Poulain
1972 Dix années d'expérimentation sur la culture traditionnelle du sorgho de décrue dans la vallée du Gorgol (Mauritanie): Inventaire des essais techniques culturales sur le sorgho de décrue dans le oualo du Gorgol, Kaédi 1960-1970. Kaédi: Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières.

Dames & Moore
1989 Senegal River Upper Valley Master Plan. Preliminary Report, Phase I, December.

1990 Senegal River Upper Valley Master Plan. Provisional Report, Phase II, July.

Davies, B. R.
1979 Stream Regulation in Africa: a Review. *In* J. V. Ward and J. A. Stanford, eds., The Ecology of Regulated Streams. Pp. 113-142. New York: Plenum.

De Leeuw, P. N., and J. C. Tothill
1990 The Concept of Rangeland Carrying Capacity in Sub-Saharan Africa - Myth or Reality. Pastoral Development Network Paper 29b, London: Overseas Development Institute.

de Wilde, John C., ed.
1967 Experiences with Agricultural Development in Tropical Africa. Vol. I. The Synthesis. Baltimore: The Johns Hopkins University Press.

Diarra, L.
1988 Changes in *Vetiveria nigritiana* and *Eragrostis barteri* grasslands in the Niger floodplain, central Mali. Bamako: ILCA.

Dunn, Ian
1990 The Effect on the Senegal River Fisheries of the Management of the Manantali Dam under Two Possible Scenarios. Report for the Senegal River Basin Monitoring Activity. Binghamton, NY: Institute for Development Anthropology.

Food and Agriculture Organization (FAO)
1988 Guidelines: Land Evaluation for Extensive Grazing. Soil Bulletin No. 58, Rome: FAO.

Gannett Fleming Corddry and Carpenter, Inc.
1978 Assessment of Environmental Effects of the Proposed Developments in the Senegal River Basin. Partial Report for Fisheries. Dakar: OMVS.

GERSAR/CACG., Euroconsult, Sir Alexander Gibb & Partners, SONED-Afrique
1989 Plan Directeur de Développement Intégré pour la Rive Gauche de la Vallée du Fleuve Sénégal. Rapport d'Etape. Décembre.

1990 Plan Directeur de Développement Intégré pour la Rive Gauche de la Vallée du Fleuve Sénégal. Document Provisoire. Juin.

Gibb, Sir Alexander & Partners, Electricité de France International, et Euroconsult
1987 Scénarios d'Utilisation de l'Eau. Rapport Définitif. Etude de la Gestion des Ouvrages Communs, Rapports Phase 2 - Volume 2A.

Gritzner, Jeffrey Allman
1988 The West African Sahel: Human Agency and Environmental Change. Geography Research Paper No. 226, The University of Chicago.

Grosenick, G., A. Djegal, J. W. King, E. Karsh, and P. Warshall
1990 Senegal Natural Resources Management Assessment, Final Report. Prepared by the Development Economics Group of Louis Berger International, Inc. and by the Institute for Development Anthropology under IQC: PDC-5517-I-13-7136-00.

Guinard, André
1988 Les activités agricoles dans la basse et moyenne vallée du Sénégal: problèmes et solutions. Report for the Senegal River Basin Monitoring Activity. Binghamton, NY: Institute for Development Anthropology.

Hollis, George E.
1990a Hydrological Issues: Part One. Report for the Senegal River Basin Monitoring Activity. Binghamton, NY: Institute for Development Anthropology.

1990b Hydrological Issures: Part Two. Report for the Senegal River Basin Monitoring Activity. Binghamton, NY: Institute for Development Anthropology.

Horowitz, Michael M
1989 Victims of Development. Development Anthropology Network 7(2):1-8.

Horowitz, Michael M, and Peter D. Little
1987 African Pastoralism and Poverty: Some Implications for Drought and Famine. *In* M. H. Glantz, ed., Drought and Hunger in Africa. Cambridge: Cambridge University Press.

Horsfield, A.
1988 A Senegal Village Water Supply Project. Journal of the Institution of Water and Environmental Management 2(4):391-398.

King, Jack Jr.
1990 A Report on Soils and Agricultural Production in the Middle Senegal Valley. Binghamton, NY: Institute for Development Anthropology.

Lavieren, B. van, and J. C. J. van Wetten
1987? Profil de l'Environnement de la Vallée du Fleuve Sénégal. Draft document. Arnhem, The Netherlands: Euroconsult.

1990 Profil de l'Environnement de la Vallée du Fleuve Sénégal. Arnhem, The Netherlands: Euroconsult and Institut National de Recherche pour la Conservation de la Nature (RIN).

Lele, Uma
1975 The Design of Rural Development: Lessons from Africa. Baltimore: The Johns Hopkins University Press.

Lericollais, André, Monica Sella, John Magistro, Madiodio Niasse, and C. Nuttall
1990 Les Relations Villes-Campagnes dans le Département de Matam. Binghamton, NY: Institute for Development Anthropology.

National Academy of Sciences (NAS)
1980 Firewood Crops: Shrubs and Tree Species for Energy Production. Washington, DC: NAS.

Niasse, Madiodio
1990 Village Irrigated Perimeters at Doumga Rindiaw, Senegal. Development Anthropology Network 8(1).

OMVS/ISTI
1990 OMVS/USAID Project 625-0958 Groundwater Monitoring Project, Final Report, Volume I, "Objectives and Outputs." Organisation pour la Mise en Valeur du Fleuve Sénégal/DIR/PES and International Science and Technology Institute, Inc., Washington, DC.

Poulain, J. F., P. Sapin, and A. Reynard
1968 Contribution à l'étude de l'amélioration des rendements du mil et du sorgho par la fumure minérale dans la vallée du fleuve Sénégal. Paper presented at the Colloque sur la Fertilité des Sols Tropicaux, Tananarive, Madagascar, 19-25 November 1967.

Reizer, Christian
1988 Les Pêches Continentales du Fleuve Sénégal: Environnement et Impact des Aménagements. Annales Sciences Zoologiques Vol. 254. Tervuren: Musée Royal de l'Afrique Centrale.

Sapin, P., and A. Reynard
1968 La culture de décrue du sorgho dans la vallée du fleuve Sénégal: Quelques techniques culturales simples pour son amélioration. L'Agronomie Tropicale 8:863-871.

Sénégal, République du (GOS)
1989 Conseil Interministériel sur l'Après-Barrages, Bilan d'Exécution du Programme d'Action, Problèmes Majeurs et Perspectives, Ministère du Plan et de la Coopération, Janvier.

Scudder, Thayer
1988 The African Experience with River Basin Development: Achievements to Date, the Role of Institutions and Strategies for the Future. Draft paper prepared for the Africa Bureau, Agency for International Development, and published by the Institute for Development Anthropology and Clark University under the Cooperative Agreement in Settlement and Resource Systems Analysis.

South Dakota State University
1982 Resource Inventory of Southwestern Mauritania: Geology, Soils, Forestry, Pasture. Report prepared for USAID. Brookings, SD.

USAID
1979 Country Development Strategy Statement FY 1981: Senegal. Dakar.

1989 OMVS 21st Meeting of the Consultative Committee. USAID/Bamako Unclassified Cable No. 8400, 15 December.

Ward, J. V., and J. A. Stanford
1989 Riverine Ecosystems: the Influence of Man on Catchment Dynamics and Fish Ecology. *In* D. P. Dodge, ed., Proceedings of the International Large River Symposium. Canadian Special Publication in Fisheries and Aquatic Sciences 106:56-64.

Watt, A.
1986 Le semis du sorgho de décrue au Fuuta: une Technologie traditionnelle de semis en zone sèche. Initiation aux Technologies Populaires No. 4. Dakar: ENDA.

Welcomme, Robin L.
1979 Fisheries Ecology of Floodplain Rivers. London and New York: Longman.

Whitely, J. R., and R. S. Campbell
1974 Some Aspects of Water Quality and Biology of the Missouri River. Transactions of the Missouri Academy of Sciences 8:60-72.

Woodhouse, Philip, and Ibrahima Ndiaye
1990 Structural Adjustment and Irrigated Food Farming in Africa: the "Disengagement" of the State in the Senegal River Valley. Development Policy and Practice Research Group Working Paper No. 20. Technology Faculty, The Open University, Milton Keynes, United Kingdom.

World Bank
1987 World Bank Experience with Rural Development 1965-1986. Operations Evaluation Department. Washington, DC: The World Bank.

1989 The World Bank and Senegal, 1960-87. Operations Evaluation Department. Washington, DC: The World Bank.

Endnotes

1. The authors, respectively Professor of Anthropology at the State University of New York at Binghamton and Senior Research Associate at the Institute for Development Anthropology, co-direct, with Thayer Scudder, the Senegal River Basin Monitoring Activity (SRBMA), funded by USAID/Dakar in a buy-in to the Cooperative Agreement on Settlement and Resource Systems Analysis. SRBMA began in 1987 and included a two-year intensive field study of three principal village sites and their productive holdings, carried out by J. Magistro, M. Niasse, and C. Nuttall, as well as shorter-term studies in agronomy and soils (by G. Dhillon, A. Guinard, and J. King), hydrology (G. E. Hollis and H. Morel-Seytoux), fisheries (I. Dunn), and social science (A. Bâ, R. Gervais, C. Howe, O. Kane, A. Lericollais, and J. Schmitz). Research assistance at IDA was provided by Curt Grimm and Monica Sella. Editorial and translation assistance was provided by Sylvia H. Horowitz, Vivian Carlip, and Françoise Thomas. The authors acknowledge with great appreciation the contributions of their colleagues to this study. The opinions expressed herein do not necessarily reflect those of the Agency for International Development, the Government of Senegal, or any other person, organization, or government. The authors may be contacted at IDA, 99 Collier Street, P.O. Box 2207, Binghamton, New York 13902-2207, USA (telephone 607-772-6244, fax 607-773-8993, telex 932433).

2. GERSAR/CACG. et al. (1990, Annexes:29) state that Flood "A" will inundate 144,000 ha of which 98,000 ha are on the left bank. They also state (1990, Annexes:19) that Flood "A" will allow for cultivation of 50,000 ha in the entire valley. With the ratio left bank:right bank=2:1, a Flood "A" would allow for approximately 33,000 ha of cultivated waalo land in Senegal.

3. IDA's hydrologist (Hollis 1990a and 1990b) demonstrates that an augmented flood released to coincide with the natural flood from the Faleme and Bakoye would require a smaller volume of water from the reservoir than Sir Alexander Gibb calculates for artifical flood "A." Hollis' analysis shows that from 1954 to 1964, the volume released would have fallen by 66 percent and from 1986 to 1989 the releases would have fallen by 19 percent. These are very significant savings of water and would provide for increased power output from the Manantali Dam.

4. The term "artificial" here means "brought about by constructive skill," that is, not solely a function of nature. It does not mean "unreal" or "imitation."

5. Sir Alexander Gibb & Partners is a member of the GERSAR/CACG. et al. consortium drafting the Left Bank Master Plan.

6. As recently as last year, the World Bank (1989:89) noted that while it had encouraged the GOS to invest in rice schemes in the Senegal valley by projecting favorable results, "there was little indication that these results were based on detailed studies of production costs nor of the likely impact of development costs on the economic cost of additional rice output."

Some instructive figures are available for the right bank of the river. In 1984 Mauritania inaugurated a vigorous program of private investment in irrigation, and over 4,500 ha. of new perimeters were developed. "These efforts have led to dramatic increases in rice production, in the order of 14,000 tons of paddy for the period 1987-88. However, the farming intensity ratio dropped from 1.06 in 1985-86 to 0.69 in 1987-88, as the amount of developed, but non-farmed, areas increased from 316 ha. to 2,114 ha" (Dames and Moore 1990:2-4, citing SAAGRER/IRM).

7. Even with government subsidies for agricultural inputs and for pumping, farmer indebtedness on lands managed by SAED is very high. By 1984, nonpayment of debts reached 255,000,000 FCFA (SAED 1986), "with the overall level of indebtedness running at a higher level on larger perimeters. This large unpaid debt was in turn a factor in persuading the state to withdraw from input and credit provision as part of the structural adjustment programme" (Woodhouse and Ndiaye 1990:7).

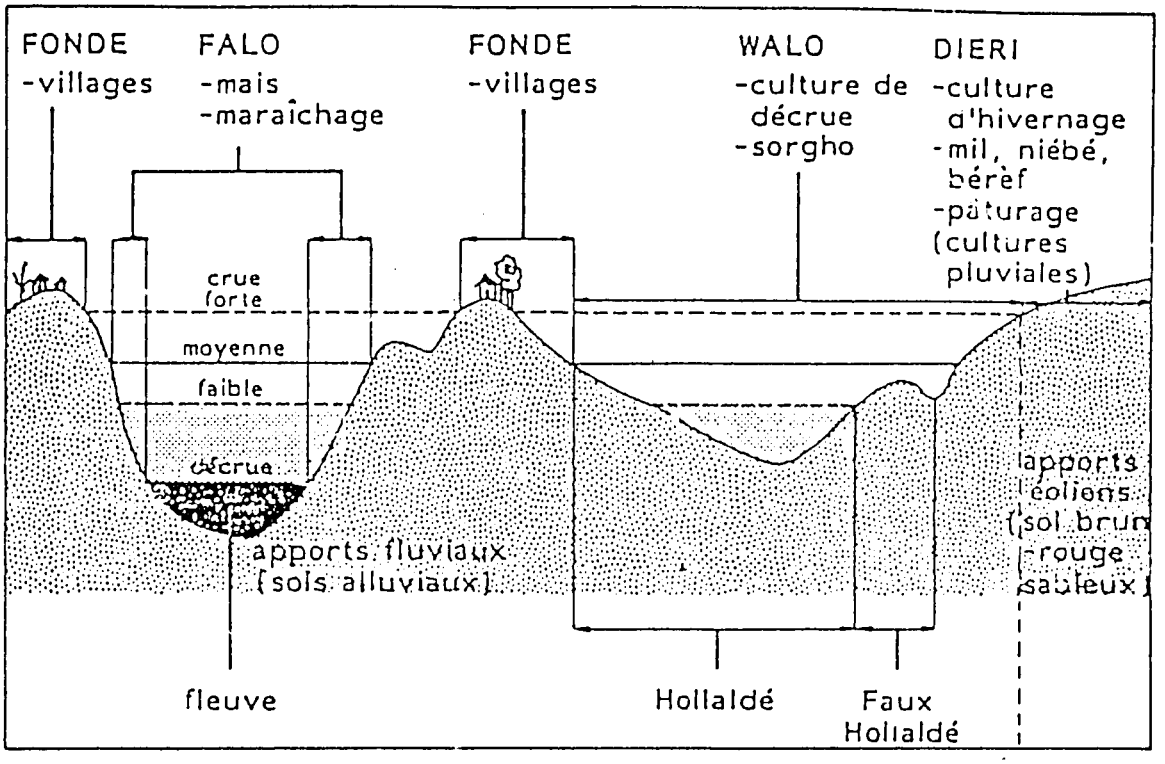
8. In Matam, the costs of a new irrigated scheme run about 840,000 FCFA/ha for a PIV and between 4,210,000 and 5,580,000 FCFA/ha for an "aménagement intermédiaire."

9. In the most current version of the PDGR (GERSAR/CACG. et al. 1990:57), the possibility of riverine transport is dismissed within parentheses: "(l'utilisation du débit garanti aux fins de la navigation n'est pas abordée dans cette étude)."

10. The principal urban agglomerations in the valley, St. Louis and Richard Toll, account for approximately 86 percent of the nonrural left bank population.

11. The term "waalo" refers both to the lateral floodplain and to flood-recession agriculture. The waalo is itself divided into three geomorphological types, each appropriate to a specific type of farming: (1) *hollalde*, the lower areas of the inundated depression that are flooded almost every year, and planted in sorghum and cowpeas; (2) *falo*, the banks of the river and marigots with rich alluvial soils, planted in maize, sweet potatoes, and other nutrient-demanding crops; and (3) *foonde*, higher elevations with mixed sand-clay soils, that are inundated only by exceptionally high floods. Jeeri soils are not flooded.

Soil Types in the Middle Valley
(after van Lavieren and van Wetten 1990:8)



12. Lericollais et al. (1990) note that as riverine fish quantities plummeted during the drought, marine fish transported by truck from St. Louis on the coast replaced freshwater species. They believe this may create difficulties for local fishers who will seek to recapture the market when normal floods lead to a resurgence in freshwater numbers. For the mechanics of fish reproduction on floodplains, see Dunn (1990).

13. See note 4. In fact, there has not been a controlled release every September. Since the dam was closed, there were very modest releases in 1987, an uncontrolled release in response to a flood inflow in 1988, and no release at all in 1990. The controlled releases have rarely been greater than the inflow at Makana. September was chosen as the latest possible time for the flood so that waters released would be those already trapped in the reservoir. Hollis (1990a and 1990b) has shown that Flood "A" almost always occurs after the peak flows in the Faleme and Bakoye, and therefore, the release does not "top up" the

natural peak on these two tributaries. As presently planned, Flood "A" will normally occur on the low and falling recession limb of the floods in the other tributaries.

14. We do not wish to imply that there is a single position embraced by all organizations involved in Senegal basin development. While OMVS focuses on the dams' contributions to hydropower, irrigation, navigation, and urban water supplies, the GOS, the World Bank, and others are also considering the impacts on the environment and on the capacity of the region to provide for a left-bank population expected to exceed 1,000,000 by the end of the century and reach 1.5+ million by the year 2015 (GERSAR/CACG. et al. 1990:21, 110).

15. Our recalculations (from Hollis 1990a) are similar to those in GERSAR/CACG. et al. (1990).

16. This section draws on field research conducted in 1988-1990. The authors wish especially to acknowledge here the work of John Magistro, based upriver from Matam at Thiemping; Madiodio Niasse, based downstream from Matam at Doumga Rindiaw; and Monica Sella, who assisted in the analysis of data.

17. The PDRG (GERSAR/CACG. et al. 1990:82) dismisses out of hand the possibility that labor availability constrains irrigated production. Noting that population growth exceeds the anticipated rate of bringing on new perimeters, they insist that "*aucun risque de manque de main-d'oeuvre n'est à craindre.*" On the other hand, the PDRG also acknowledges (ibid.:118) that flood-recession cultivation is attractive to farmers because it is capital and labor saving: "*les cultures pluviales et les cultures de décrue n'engendrent pas de charges monétaires, ce qui permet de les engager sans risques. En outre, elles sont peu exigeantes en main-d'oeuvre . . ..*"

18. Production figures refer to decorticated rice and not to paddy, and the data are for the 1988 season in Doumga Rindiaw and the 1989 season in Thially. Sorghum figures are for 1989. Two sets of prices for sorghum and rice are utilized to account for the varying prices farmers received depending on when grain was sold and to whom. Net output figures are calculated by subtracting land use and cash input costs from the value of gross output/hectare. No labor costs are imputed. This approach is based on actual prices paid and costs incurred, and therefore leaves less room for research bias than do conventional calculations that impute values to unpaid inputs. Returns to capital are calculated by dividing gross output value/hectare by production outlays/hectare. Net labor output is calculated by dividing net output/hectare by the number of person-days/hectare.

19. Boyenadji Roumde, downstream from Matam, was studied by Christophe Nuttall.

20. The PDRG notes a variety of rates of intensification, from a high of 88 percent (p. 86) to a low--"*le taux actuel de mise en valeur des aménagements*"--of 70-80 percent. SAED's figures for intensification rates on rice perimeters in Matam are much lower. In 1978, of 1,095 hectares prepared for irrigation, only 299 or 27 percent were actually cultivated. In 1979, 42 percent were cultivated; in 1980, 64 percent (a figure never again attained); in 1981, 59 percent; 1982, 43 percent; 1983, 44 percent; 1984, 44 percent; 1985, 40 percent; and in 1986, of 4,997 hectares prepared for irrigation, only 1,740 hectares or 35 percent were actually in paddy.

21. "*Dans les cuvettes de plaine d'inondation des graminées pérennes comme* Oryza longistemmata, Echinochloa stagnina *et* Vossia cuspidata *constituent une ressource alimentaire très importante pour le bétail. Ces cuvettes, ressemblant à des 'bourgoutières', sont aussi d'une grande importance pour les poissons et pour l'avifaune*" (van Lavieren et van Wetten 1990:10).

22. The concept of "carrying capacity" (CC) is controversial, and estimates for a particular rangeland vary widely because of (often) unstated assumptions about what it entails. De Leeuw and Tothill (1990:2, following FAO 1988) define it "as the maximum possible stocking of herbivores that rangeland can support on a sustainable basis. . . . Estimates of CC are commonly based on the assumption that livestock require a daily dry matter (DM) intake equivalent to 2.5% to 3.0% of their body weight. Thus, for a TLU of 250 kg of weight, 2.3 to 2.7 t of dry feed per annum is needed. To calculate an appropriate balance between forage supply and demand three multipliers are additionally required to adjust for: (1) grazing efficiency (the proportion of total herbage livestock can harvest; (2) forage loss (due to trampling, fouling, decomposition, etc.); (3) proper use, which is the maximum proportion of forage that can be grazed without causing rangeland deterioration. . . . Although each of these three factors need consideration, most estimates have used a single multiplier that combines adjustments for all." For a review of the controversy about the meaning and utility of "carrying capacity" as a guide for action, see Horowitz and Little (1987; see also Barrett 1989).

23. The uncontrolled flows from the Bakoye and Faleme tributaries will continue, and these are sometimes sufficient in themselves to constitute a good flood. During wet periods, such as 1954-1964, the aggregate flows from these unregulated tributaries would have exceeded artificial Flood "A" in almost every year. In dry periods their flows are too low. The drought since 1972 has reduced the contribution of both tributaries to the combined flow at Bakel.

24. We do not have clear understandings of the fertility value of manure on Senegalese cultivated fields, although for one area in Mali, "Wilson (1984) estimates increased yields of

three to five times over unmanured, periodically fallowed fields. . . ." (Grosenick et al. 1990:115). The nitrogen content of the manure is highest when animals have browsed relatively fresh high-quality forage, such as still-green sorghum stalks on *waalo* fields that have just been harvested. This manuring is the only external fertilization these fields receive. Livestock--both transhumant and locally owned agropastoral herds--probably contribute importantly to the productivity of flood-recession cultivation, although the magnitude needs to be documented with empirical study.

The herds also contribute to the productivity of floodplain fisheries. "The dung dropped by the cattle, estimated at about 500 kg $hm^{-2}yr^{-1}$ . . . converts much of the dry-season primary production into readily dissolved organic and mineral nutrients which have an important impact on the chemistry of the floodwaters . . . " (Welcomme 1979:238).

25. ". . . *la régénération naturelle des Gonakiés exige une inondation temporaire de graines*" (van Lavieren and van Wetten 1987?:43).

26. ". . . in arid regions of India, [*A. nilotica* constitutes] the chief diet for goats and sheep. Pods contain as much as 15 percent crude protein" (NAS 1980:98).

27. Although biodiversity is not a topic that SRBMA has been able itself to investigate, there is evidence that the *A. nilotica* forests contribute to an impressive range of wildlife in the region: "*L'importance des peuplements de gonakiés comme habitat recherché par plusieurs espèces de faune, mammifères aussi bien qu'oiseaux, est indéniable. La majorité des espèces de mammifères qui survivent dans la région du fleuve y trouvent abri et nourriture. Plusieurs espèces d'oiseaux font leurs nids dans les arbres. Le déclin des surfaces de peuplements de gonakiés a donc également un impact négatif sur la faune de la région*" (van Lavieren and van Wetten 1990:42). One might speculate that if the reduced flood leads to a reduction in natural floodplain vegetation, the remaining birds will have no recourse but to attack the standing grain, increasing preharvest losses. Gritzner (1988:71) points out that large quantities of rice on major Senegal Valley irrigation schemes were consumed by "black-faced diochs, long-tailed glossy starlings..., knob-billed geese, and other granivorous birds, as well as insects and rodents..."

28. As argued by Hollis (1990b), the incorporation of data from the upper catchment in Guinea is critical for effective management of the Senegal River Basin. It is important, for example, to understand the rate and downstream effects of deforestation in the Guinea Highlands and the Fouta Djallon. "There is an abrupt rise and fall of flood peaks in the absence of the buffering effects of a wooded catchment" (Ward and Stanford 1989:60).

29. It was hoped that the OMVS Groundwater Monitoring Project, which operated from January 1985 through June 1990 with a hydrogeological observation network of some 500 village wells and 569 piezometers located in the Senegal Valley west of Bakel, would have provided firm evidence on how these aquifers are recharged. Although much raw data was collected, according to the project's final report, time did not allow for analyses other than for the delta and Manantali regions. It goes on to note that a topic remaining to be studied is "the natural recharge of alluvial aquifers and deep aquifers underlying the Senegal River valley" (OMVS/ISTI 1990:1). Since the data and an appropriate computer program are available at OMVS in St. Louis, it is to be hoped that such a study will be undertaken in the near future.

30. GERSAR/CACG. et al. (1990:69) note the cost (in milliards FCFA) of equipping villages in the Podor area with boreholes is 4.5, in Matam 5.0, and Bakel 1.3. Their total is 11.8 x 10^9 FCFA.

31. The effects on potable water supplies of terminating the Senegal flood may be felt first in the delta region, for example, in the city of St. Louis, where the shallow aquifer is already saline and the "sweetness" of the deep aquifer may depend on pressure from the flood.

32. In this report we have not considered the health and nutritional costs of the changed water regime. It is clear that across tropical Africa, the extension of irrigation has led to increased frequency of malaria and schistosomiasis--"*les casiers d'agriculture irriguée constituent un habitat idéal et permanent pour la prolifération des moustiques*" (van Lavieren 1987?:12)--and possibly to impoverished nutrition, especially of infants and pregnant and nursing mothers if the schemes have a negative impact on the food supply. It is important not only that the relationship between disease vectors and river basin development be understood, but that effective and timely mitigative actions be taken. Unfortunately, states and donors who readily invest in the infrastructure of irrigation are much less enthusiastic about equipping the schemes with sanitary facilities or assuring that monocropping and heavy reliance on agricultural chemicals do not adversely affect nutrition and health.

33. This review of Sir Alexander Gibb's material draws heavily on work by IDA senior research assistant Curt Grimm and by IDA consultant hydrologist Dr. G. E. Hollis.

34. Note that we, and Gibb, are working with monthly averages. It is possible that daily flow data might demonstrate that the peaks during those months were indeed sufficient for the flood, although the cumulative data for the month appears to be deficient.

35. The recommendations listed do not consider technical approaches to increasing productivity on irrigated schemes, not because we believe that nothing can be accomplished, but rather because this is already the object of a good deal of research in the valley. We do insist, however, that the sociological and institutional dimensions of irrigation have generally been ignored, and that these merit a good deal of attention in the future.

36. A detailed discussion of the recommendations dealing with water will be found in Hollis (1990a and 1990b).