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Pollution and ecological changes in Lac de Guiers, North Senegal: Impacts on environment and health in the context of future water resources projects

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1 INTRODUCTION

The Senegal River Basin has already experienced decades of hydraulic works development and installation of irrigated perimeters. The control of water resources is now completed with the construction and operation of the Diama and Manantali dams. The pace of natural resources exploitation is far beyond initial plans while environmental degradation, health epidemics (especially bilharzia) and anthropological conflicts have spread into agricultural schemes.

To face and correct the situation, the Left Bank Development Plan and a Health Master Plan have been completed and have reached the implementation phase. Furthermore, a new cycle of water resources development projects initiated by the Senegalese Government plans to take benefit of the controlled waters in order to promote environmental regeneration of drought-affected ecosystems and revival of other regions for agriculture.

The new strategy takes the Lac de Guiers as a central water body that would become the starting point for all hydraulic works such as the Canal du Cayor and Revitalisation des Vallées Fossiles. However, the lake presents signs of eutrophication and of water-associated diseases endemicity that can be transferred to other parts of the country via canals and revived hydrographic networks.

This report analyses the current environmental situation in Northern Senegal, especially in Lac de Guiers with regards to water quality, aquatic vegetation, diseases vectors and prior guidelines for prospection of future impacts of human intervention are provided by using a computer model.

The general process of future projects are visualized as follows: water transfer -> change in original hydrological regime -> change in the natural environment -> change in the social economy (condition of production). The impact may be divided into three different geographic regions, namely, the exporting, transfer, and importing regions. However, with the exception of the Canal du Cayor Project where the three component areas are quite distinctive, for any other project the transfer and importing regions are confused since the topographic configuration does not allow the constitution of final storage reservoirs. The revived rivers will join perrenial streams such as the Saloum and Casamance rivers.

Given the importance of such projects for the development strategy of the country vs potential environmental and health issues, development assistance from donors can be directed at environmental planning as integral part of the investment process in order to secure sustainable development.

2 STATEMENT OF THE PROBLEM

2.1 HISTORY OF RESOURCES DEVELOPMENT

The management of the lake started as early as 1916 when a earth dam was built on the Taouey tributary to prevent saltwater intrusion during the recession stage. Since then, the building and improvement of public works has progressed in order to control both water entries and distribution.

In 1947, a bridge/dam was constructed on the Taouey tributary to replace the earth dam and improve the storage of freshwater for rice cultivation purposes. The Nieti Yone river which connects the Guiers to the Ndiael depression was also disrupted by the construction of a dyke.

In 1954, the Keur Momar Sarr dyke was built in the South to isolate the lake from the Ferlo valley.

From 1970 to 1985, the increase of water needs foor agriculture and urban supply lead to new projects and improvements:

- The water authority SONEES built a water plant on the eastern shore and a twin-pipe system was installed for water transfer to Dakar in 1970
- The Taouey channel was straightened in 1974 for the purpose of improving the reservoir filling and a proper supply of sugar perimeters run by CSS
- In order to reduce its dependence on Lac de Guiers, the Sugar Company built a second bridge/dam on the Taouey Channel in 1980. The new system allowed them to pump either from the lake or directly from the river.

2.1.1 change in natural flow

The hydrology of lac de Guiers is characteristic of that of a natural distributary system because of its connection to the Senegal River;

- The mean level is close to 0.38m IGN with a maximum water level of 1.81m corresponding to a volume of 600 million m^3. During the severe drought of 1982/83, the lowest level of -1.48m was recorded. The annual deviation between maximum and minimum flow levels is as high as 2.09m with a highest record during the hydrolgical year of 1982/83.
- The relation to Senegal River, the instability of water levels and the lake morphology induced important historical fluctuations and approximately 150 km^2 of the lake bottom land is annually discovered.

The construction and operation of Diama Dam from 1985 introduced a substantial change to the hydrology of the lake:

- The mean level has raisen to 1m while the annual difference between extremes dropped to 1.64m because of the influence of the Diama Dam.

The permanent availability of sufficient water in the Diama Reservoir will ensure a high mean level and low amplitude due to the possibility to fill the lake many times a year. However, this hydrologic situation will probably trigger economic, health and ecological risks.

2.1.2 water utilization

At 1m above sea level, the lac de Guiers cover an area of about 240 km^2 for a water volume of 390 million m^3 and a mean depth of 1.63m. The lake is quite flat and its bottom is at only 2m below sea level. This morphology facilitates water exchanges between the Senegal River and the lake and explains the salt water intrusion phenomenon at low fluvial regimes.

Before the Diama Dam, the lake waters were essentially used for developping an irrigated agriculture (rice by SAED and sugar crops grown by CSS) and for supply to Dakar by SONEES. The support to rural economic development was also a noticeable role through vegetable growing and livestock breeding.

Nowadays, after the satisfactory flow regulation of the Senegal River through simultaneous operation of Diama and Manantali dams, the main users are still CSS, SONEES and irrigated agriculture but the design of new water transfer projects by the Senegalese Government will certainly change priorities and confer more importance to the lake within the national policy of hydraulic resources development.

There are three major projects which are described below.

2.1.3 reflooding of the Ferlo valley

The Ferlo valley is a natural extension of Lac de Guiers to the South. It is a dried hydraulic network which is separated from the lake by the Keur Momar Sarr dyke. The reflooding of the Low Ferlo was started in 1988/89 and the floods extends now to Linguère in 1994. The reflooding of the entire Ferlo valley will be in two steps:

- Revival of the Lower Ferlo from Lac de Guiers, up to Linguère (150 km)

- Revival of the Upper Ferlo by direct water transfer from Senegal River by dredging a junction channel from Bakel and reprofiling of 300 km of natural channel.

The operation is a start for a larger government project called Programme de Revitalisation des Vallées Fossiles run by the Mission d'études et d'aménagement des vallées fossiles of Ministry of Hydraulics. The total length of river will be around 3000km and will cover 6 fluvial systems; Ferlo valley, 1200km; Sine, 250km; Saloum, 300km; Carcar 300km; Baobolon, 100km and Sandougou.

The reasons for this effort are twofold; socio-economic reasons and, resources development and utilization.

Socio-economic reasons relate to agricultural development and improvement of rural economy by increasing food production and diversifying activities. The project will allow to transfer water to zones with a high agricultural potential, thus enabling an intensification and diversification of crop production. Other benefits are foreseen in terms of reduction of population drift to urban zones and environmental improvement by afforestation and ecosystems stabilization.

Since Senegalese agriculture is essentially rainfed and crop production is limited by rainfall varaibility, the optimal use of the water volume allocated by OMVS is of prime importance in terms of development policy. Actually only 60% of discharges are retained and regularized by the Manantali and Diama dams and the additional 40% is wasted into the ocean. The optimal use of the floodwater of Senegal River Basin would cover the needs of the three major left bank projects that are the Left Bank Master Plan, the Canal du Cayor and Vallées Fossiles.

2.1.4 reflooding of the Ndiael

The Ndiael is a wide siltation basin (sebkha) located at the margin of the delta of Senegal River, on the western shore of Lac de Guiers. Until 1950, when the first hydraulic works of the delta began to operate, the Ndiael functionned as an alternately filled pond. It is linked to the Lac de Guiers by the Nieti Yone distributary and to the estuary by the Menguèye river. The bottom of the basin is alternately submitted to either eolian processes or siltation when under flood conditions, the basin fills up with water. Recent permanent exondation has allowed the mobilization of subterranean salts which can form a 5 to 10 cm thick surface layer.

The reflooding operation is planned within the Left Bank Master Plan for 1100 millions FCA (1994-2000). The main costs will be related to the endikements of distributaries and dredging the natural channels. About 100 to 200 millions cubic meters of water can be stored with the purposes of regeneration of the ecosystem, the institution of a faunal reserve and the socio-economic development of local communities.

The main issues attached to this project relates to conflicting objectives. The benefits for different partners are not necessarily the same in terms of priority and spatial perspectives. The issues resume to conflicts for water between socio-professionnal groups (livestock raisers, farmers and fishermen); divergence between communities and other sectors such as tourism, hunting and wildlife management; conflicting planning targets between wildlife managers and land development planners.

This project is a sample of the national water resources development policy for the next century. The aim of this policy is to revive all the hydraulic network for rural development, water supply and environmental management by transfering water from the Senegal River.

2.1.5 Canal du Cayor project

Currently, the city of Dakar is being supplied from Lac de Guiers by a pipe system from the Ngnith pumping and treatment plant situated in the western shore of the lake. The rapid growth of the urban population has conducted to a water shortage and has made the design of the Canal du Cayor a necessity.

The new Canal du Cayor Project is an open canal from the southern part of Lac de Guiers to Dakar. The canal and proposed pumping stations, treatment plants, and distribution systems will provide a high quality potable water supply system to Dakar and the metropolitan area, with a design figure of 100 liters per capita per day for residential connections (Diop et al. 1995).

The source of the proposed expansion of the supply for Dakar from Lac de Guiers and therefore from the Diama Reservoir, and because of the design of the canal and of the industrial plants along in the area, a detailed study of potential water quality problems in Lac de Guiers is strongly recommended. Furthermore, potential health problems, especially spread of Bilharzia along the projected canal should be studied as sources of serious threats to health of populations of Dakar and along the route of the canal.

3 POLLUTION TRENDS

Since 1990, major cases of food and water poisonning are being reported from the Senegal River Basin, especially in the Richard-Toll area and are presumably related to the uses of fertilizers and pesticids in agribusiness that contribute to the deterioration of water quality within the basin area. Identification of sources and quantification of pollution levels are not well documented despite the noticeable effects on aquatic ecology and drinking water quality.

3.1 ORIGIN OF POLLUTANTS

Water quality in Lac de Guiers depends on the quantities of water supplied by SRB, drainage water from the sugar cane perimeters and to a lesser extent on the contribution of overland flow versus losses by evaporation and water pumping by CSS (and other agribusiness), SONEES for urban water supply and the flooding of Ferlo valley.

3.1.1 the SRB

The Senegal River contributes 90% of the water stored in Lac de Guiers and therefore can carry large quantities of pollutants, mineral and organic material washed out from gold mines in the Fouta Djallon area and also from irrigation along the middle and lower reaches.

The town of Kayes situated in the upper valley in Mali has once recorded high concentrations of presumably arsenic and mercury during the first stage of flooding when overland flow and runoff reaches the river with high turbidity.

Furthermore an increasing use of pesticids and fertilizers accompany the recent booming of privately owned medium size rice perimeters in the middle valley and especially in the Mauritanian side where no pesticid control is exerted

An evidence of the supply of pollutants to lac de Guiers from SRB is given by the proliferation of Pistia stratiotes, an algae that has a riverine origin.

3.1.2 CSS wastes

They represent 5% of water volumes stored into Lac de Guiers and contribute substantially to the salinization of the reservoir water. Drainage water has a salinity varying from 800 to 1300 mg/l and a chlorinity around 200 - 300 mg/l (ORSTOM records). Lake water contains at some of the measuring stations, high quantities of sulfates originating from the use of gypsum for desalination of soils. The drainage water contains also residus of fertilizers such as phosphorus and nitrogen that contribute to the eutrophication of the lake by causing rapid and extensive algal blooms.

3.1.3 runoff waters

Their importance is quantitatively negligible as they contribute only 5% of the stored volume. However, they can carry pesticid residus washed out from irrigated perimeters on the eastern shore of the lake. Furthermore, large quantities of organic material can reach the lake bottom from small vegetable plots all around the lake.

3.2 THE EUTROPHICATION PROCESS

3.2.1 water quality and pollution levels

Recent algal blooms indicate a process of eutrophication in relation to the development of irrigated agriculture around the lake. The process originates from changes in the hydrological cycle introduced by flow regulation by Manantali and Diama dams, changes in control gates operation (i.e. reduction of water circulation and velocities imposed by the Taouey and Keur Momar Sarr control gates) and supply of phosphorus and nitrogen by residual waters from irrigated perimeters and industrial plants.

Comprehensive assessment of pollution levels has not yet been done with the exception of erratic measuring efforts from ORSTOM scientists. The studies are principally orientated towards the understanding of the physical and chemical characteristics of lake waters (Cl, SO4, Ca, Mg, Na, K, total anions and total cations) and the spatial variation of water quality. The data can however give a genuine idea of potential pollution threats and can help also explain the trends in aquatic vegetation changes.

The ORSTOM data indicate a remarkable difference between the northern and southern parts of the lake. Until 1988 when the reflooding of the Ferlo occurred by openning the southern gate, the mineralization of the southern part was higher than that of the northern part of the lake. The shallow lake bottom and high daily evaporation rates contributed largely to the 4 to 5 times higher mineralization (essentially chlorines and natrium). Since the operation of Diama dam, the concentration of dissolved elements has dropped 10 to 30% in the North and 40 to 60% in the South.

In other hands, the total amount of salts has increased from 76000 tons before Diama to 84000 tons after Dam completion. This increase around 19% is occuring because of accelerated deposition in the North from drainage water pumped into the lake by the sugar factory (CSS). Therefore, the diminution of the concentration of dissolved elements does not significate a reduction of salinisation but their dilution due to an improved filling of the reservoir.

3.2.2 changes in aquatic vegetation

Under undisturbed natural conditions, the aquatic vegetation of Lac de Guiers is dominated by Typha australis which is an indicator of fresh-to-slightly brackish water.

Since 1985 and subsequent to the operation of the Diama Dam, the lake water has been maintained to an almost stable level with a reducted water circulation. This newly imposed management conditions dictated by the aim of satisfying the needs for irrigation has triggered the development of Pistia stratiotes a freshwater floating weed which obstructed the southern part of the lake in 1992. Therefore, the openning of the Keur Momar Sarr gate in 1992 was primarily aimed at flushing the weeds out of the lake to the Ferlo valley.

In the northern part of the lake, new algal species characterizing eutrophic lake conditions such as Potamogeton schweinfurthii, Ceratophyllum demersum, Anabaena spiroides and Microcyctis aeruginosa appeared since 1990 and tend to replace the normal vegetation of Nymphoides ezannoi and Aeschynomene elaphroxylon decimated by herbicids wasted out of the sugar cane perimeters.

Cogels et al. (1993) stated that the eutrophication process of the lake can be partially attributed to the remobilization and dissolution of the phosporus trapped into lake bottom sediments but the major contribution is from irrigated perimeters (2500 hectares) that proliferate since 1990 due to the permanent availability of irrigation water.

The benefits from new water resources development projects are strictly related to the improvement of water availability for irrigation. From an ecological standpoint, the quality of water and changes in aquatic vegetation point to a rapid eutropication of the lake which can impede other water transfer projects while causing serious threat to human health, ecological stability and possibly to irrigation in longer term.

4 EFFECTS OF DEVELOPMENT ON HEALTH, ENVIRONMENT AND RESOURCES

4.1 DROUGHT AND WATERLEVEL FLUCTUATIONS

Since the middle of the 19th century, the hydraulicity of the Senegal River has progressively decreased. Figures given by Orstom (Olivry et Chastanet, 1989) on the basis of extrapolated and quantified historical information from 1850 to 1985 show a constant decrease of mean discharges:

1850 to 1900, Mean Annual Discharge = 800-930m^3/s (50 years)

1850 to 1985, Mean Annual Discharge = 780 m^3/s (128 years)

1900 to 1985, Mean Annual Discharge = 710 m^3/s (83 years)

1935 to 1985, Mean Annual Discharge = 660 m^3/s (50 years)

1955 to 1985, Mean Annual Discharge = 620 m^3/s (30 years)

1970 to 1985, Mean Annual Discharge = 420 m^3/s (15 years).

Within a hundred-year timespan, available water resources have been cut to half of their volumes. This general trend is complicated by severe episodic multi-year droughts which affected natural resources and therefore livestock and human communities. The most severe droughts are 1911-1917, 1939-1947 and 1971-1985. Though, the return of wetter climatic and hydraulic conditions seems to be encroached since 1985.

In the context of decreasing rainfall, the reliance of local community survival on surface water resources seems to be the only sustainable solutions and therefore much investment efforts have to be put on structuring public works that regularise flow regimes.

The recognition of the basin's fragile ecology and precarious human conditions dramatically demonstrated by the droughts and famine of the 1970s and 1980s have favored the creation of the OMVS (Organisation pour la Mise en Valeur du fleuve Sénégal) (Diop et al. 1994). However, there are many new problems that entail development by threatening the quality of resources and human productivity.

4.2 EVAPORATION

Evaporation is a key parameter to the water budget and the development of a model for sustainable water management in the new context of supplying the overall country from the lake.

Evaporation rates are 6.25 mm per day and 2.28 m per year with the same pattern as that of other western sahelian lakes. The daily maximum is recorded in May (dry season); the low being recorded in July, August and September corresponding to the rainy season.

High evaporation rates and the shallowness of the lake bottom cause serious losses of water volumes at high storage levels. This process is significant in terms of sustainable management of lake waters and therefore the filling of the lake has to be maintained at a level that allows a reduction of evaporation.

4.3 IMPACT OF WATER HARVEST AND TRANSFER ON ENVIRONMENT AND HEALTH

As a major source for forthcoming water development projects described above, Lac de Guiers offers best conditions for studying potential impacts on health and environment as the same hydraulic conditions are bound to prevail all along major projected watercourses.

The overall flow conditions are strongly dependent on modifications of the Senegal River regime which is strongly controlled by the Diama and Manantali dams. From Saint-Louis to Dagana and further upstream, the floodplain ecology has evolved from deltaic and riparian to lacustrine conditions. The lac de Guiers and other depressions are managed and maintained at constantly high water levels and water quality has evolved from alternately brackish/fresh waters to year-round freshwater conditions. The modifications have substantial impacts on ecology, groundwater flow and on health and - through water availability - on human activities.

4.3.1 impacts on environment

From Diama Dam in the West to Dagana in the east, the river has been transformed into a relatively stable lake with no more flooding or salt water intrusion. This stability has promoted extensive emergent weed growth of *Typha australis, Cyperus articulatus, Polygonum senegalense, Vossia senegalensis and Paspalum vaginatum*.

The dense aquatic vegetation is an effective barrier against water circulation, wind and wave action and provide suitable habitats for disease vectors (mosquitoes and snails). The two dams have created similar environments at lac de Guiers as studied above and Gorom-Lampsar rivers.

In longer term, under the current Senegalese water resources development policy, the overall network of dry valleys will be revived by making best use of the water resources from SRB. The economic argument of such a policy (improvement of production systems, mainly agriculture) is justified. Nevertheless, success of failure will be highly dependent upon prior planning and effective mitigation of potentially negative environmental and health impacts.

Water availability will promote irrigated agriculture. This will trigger the need for more irrigation and drainage canals which will host the same ecological conditions, thus multiplying the water contact points and sources for intoxication or infection of local communities.

4.3.2 impacts on health

As a direct consequence of the completion of the Diama and Manantali dams, the rise in prevalence and intensity of bilharzia occured because of the lack of corrective measures during the design stage of these hydraulic works despite prior study efforts (e.g. Gannett Fleming study, 1982). Modifications of other prevalences of malaria and potential development of Rift Valley Fever epidemics have also being reported (Senegal River Health Master Plan Study, 1994).

The two main species of trematode, the parasite responsible of bilharzia infection, Schistosoma mansoni (intestinal form) and Schistosoma haematobium (urinary form) are endemic in the Senegal river basin, including Lac de Guiers. In addition to human forms of infection, other veterinary species of the parasite (e.g. Schistosoma bovis which is prevalent in cattle) are also endemic. Each of the species depends on a compatible species of aquatic vector snail to perpetuate its life cycle. In the area of Northern Senegal, Biomphalaria pfeifferi and different species of Bulinus (Bulinus truncatus mainly for the veterinary parasite of Schistosoma bovis) are the respective host snails of the intestinal and urinary forms of bilharzia.

Data on prevalences have been captured since 1980 and new trends have been summarized in the OMVS health status report. Since 1989, intestinal bilharzia was unknown in the Senegal river basin while the prevalence of the urinary form was generally low in the Delta. The reason for low prevalences of urinary bilharzia relate to the inhibition of the development of vector snails by seasonal salt water intrusion.

The completion of Diama Dam drastically changed the epidemiology of the disease. Intestinal bilharzia reached Richard-Toll in 1988 and increased to epidemic proportions the following year. By 1993, nearly 100 percent of the residents of nearby Ndombo village were found to be infected with heavy egg loads.

In 1994, surveys made during the Health masterplan Study at Dagana (Senegal River) and Mbane (Lac de Guiers) showed still low prevalences of urinary bilharzia but extremely high prevalence of intestinal bilharzia at lac de Guiers with 82% and medium count at Dagana (47%). These figures are the highest ever obtained for the lower and middle reaches of the valley. Although no urinary bilharzia was found in Dagana, uninfected specimen of Bulinus globosus indicate that increased irrigation with open canals could lead to the establishment and rapid spread of the urinary form of the disease.

The status of malaria seems to be different of that of bilharzia. No evidence of a direct linkage between water resources development and malaria transmission was ever found.

4.4 IMPACT ON RESOURCES DEVELOPMENT

4.4.1 urban water supply

Since the Canal du Cayor project receives high consideration from government agencies, its implementation will reinforce water availability in cities along the canal, i.e. Louga, Thies and Dakar. The potential threats are related to a rapid deterioration of water quality as large scale irrigation schemes will be developped and will probably provoke pesticid returns to the open ditch. Furthermore, in-channel vegetation growth would reduce velocities to less than 0.35 m^3/s which is the threshold for proliferation of snails vectors of bilharzia. These snails exist in Lac de Guiers and could rapidly disseminate along the canal. Therefore, the installation of treatment plants in each city is a prerequisite to water consumption by urban communities.

4.4.2 rural sewerage and water supply

The rural communities are generally supplied from wells equipped and maintained by Ministry of Hydraulics. These wells are strongly affected by successive drought phases and the construction of Canal du Cayor and Revival of the hydrographic network would encourage direct consumption of open and unsafe waters. Along the design process of the canal, the improvement of sewerage and water supply systems within the Valley and Lac de Guiers area should also receive high priority in order to sustain health and tackle the unequity issue related to resentment from local communities about water transfer to urban areas while they face serious threats to health and environment as outcome from these projects.

4.4.3 livestock and agricultural activities

Livestock breeding is the major activity within the Ferlo area and Southern Lac de Guiers. The revival of the Ferlo valley and Lougeré tributary by boosting water availability will have significant impact on livestock development and therefore on natural resources management.

A kernel issue should be raised about potential development of irrigated agriculture and its competition with livestock breeding for water, space and (human) resources. Therefore land allocation and uses have to be directed by area-specific master plans to allow sustainable resources development.

The revival of the Ferlo valley (since 1992) has not yet resulted in agricultural development (as previously forecasted) because of the low numbers of inhabitants and lack of investments, the experience of conflicts between livestock and agriculture exists on the eastern shore of Lac de Guiers. The fenced CSS sugar perimeters prevent cattle from accessing the lake. The Sugar Company finally installed cemented basins outside the perimeters to resume conflicts.

The water projects will also disturb the traditional north-south and east-west transhumance circuits. The mobility of cattle and their herders is part of a well mastered strategy of rangeland management in sensitive ecosystems such as that of the Sahel. Water availability will encourage fixation and settlement in longer term. Therefore, Cattle numbers will increase and exploitation of pasture land will intensify to conduct to rapid soil erosion and land degradation.

5 IMPLICATIONS FOR FUTURE DEVELOPMENT PROJECTS

Land grabbing by government and private individuals has further threatened the livelihods of individuals (see World Bank paper; An environmental strategy for the Sahel, 1993) who also bear all of the environmental and health costs. In all cases, resources development would be based on private investment and heavy schemes detrimental to small scale projects; state intervention concerning only basic infrastructure (dams, dykes, etc). That is the case in Northern Senegal. Although, it is not a totally wrong policy, careful planning integrating economic analysis, social trends and environmental concern has to be implemented in the early design stage.

In the Senegalese case, the overall future development strategy being based on water harvesting and transfer from the Senegal River Basin to implement the Canal du Cayor and Revival of the Hydrographic Network, we have tested three main Scenarios of development options as a direct consequence of these projects. The scenarios are:

1 Large scale irrigation,

2 Livestock development projects,

3 Forestry projects (including the option for social forestry).

The planning tool used for analysis is **ECOZONE** a knowledge-based computer system developped by FAO for training in environmental impacts of agricultural projects. The environmental impacts generated by the programme are simulated up to a fifth degree of significance

The results are presented in this report to help orientate environmental planning and therefore investment decision making. The listing can be discussed by an expert panel in order to seriate and determine the most likely impacts, their magnitude in accordance with project specifications and their seriousness.

The computer simulation provides also opportunities to investigates best available options for mitigation in relation to a user-defined project appraisal procedure.

6 CONCLUDING REMARKS

There is a need to sustain the state efforts at developing the potential of natural resources by reducing the dependence of production systems upon rainfall in dry Sahelian ecosystems. Therefore, the optimization of the use of the water volumes allocated by OMVS from the Senegal River Basin seems to be a reliable policy orientation which can be directed towards sustainable development if environmental, social and health issues are taken into account and corrected in the design stage.

4 kinds of actions can be suggested:

- Implementation of the Senegal River Health Master Plan for OMVS which include a disease vector control programme prior to the installation of the turbines at Manantali Dam for electricity generation.

- Environmental and Health Assessment of the already refilled Ferlo Valley and Lougere branch. The terms of reference are being drafted by the consultant for the Mission de Revitalisation des Vallées Fossiles.

- Rehabilitation of aged irrigated perimeters including a vector control programme and other environmental and social considerations.

- Tailoring of Development Plans specific to hydrographic zones prior to their revival. The study should also address land tenure and allocation systems.

Based on the budget allocation drafted for the Ferlo and Lougere Environmental Project, it is wise to allocate 10% of total project investments to the study and implementation of environmental plans.

The consultant posesses valuable environmental impact assessment tools such as ECOZONE and reliable expert panel to help design environmental plans or screen demands for investments in natural resources development in order to either optimize project output or orientate JICA's cooperation areas and prevent environmental disasters.

Simulation of the potential impacts of water transfer projects and induced development in Northern Senegal using ECOZONE.

1 DIRECT IMPACTS OF WATER TRANSFER PROJECTS

1.1 IMPACTS ON WATER-EXPORTING REGIONS

The negative impact on the water-exporting region occurs in the low water season and results in shortages of water for uses i.e. hydropower generation and agriculture. The positive impact is the improvement of flood damage mitigation during the flood season in wet years. This impact can be extremely beneficial during exceptionnally wet years or in case of accidental events.

1.2 IMPACTS ON WATER TRANSFER AND IMPORTING REGIONS

The major problems are potential changes in chemical matter and water quality along the main canal, the spreading of water-related diseases, and changes in the hydrological regime and therefore in environment. Salinisation and swampiness may develop along the main canal and seepage can cause the groundwater table to rise substantially. A potential benefit would come from the increase of fish production.

Secondary salinisation by waterlogging is a serious problem that necessitates knowledge of groundwater and soil conditions, and a surveillance plan of drainage in irrigated areas. Salinisation will determine the success or failure of the project.

Furthermore, there will be changes in the microclimate (essentially an increase in soil moisture) that can affect -cultivated- plant growth. The radiation balance of the ground and crops should be studied and compared to exactly determine the effects of microclimate.

2 THE ECOZONE SOFTWARE

2.1 SOFTWARE SETTINGS

The ECOZONE software is a composite of three systems, a workshop, an impact analysis system and empty books. The systemes were developed around the same rulebase and possess similar interfaces. ECOZONE recognises three geographical regions -upland, lowland and coastal- and two climatic regimes - arid and humid. It also recognises five sectors -Agriculture, Aquaculture, Forestry, Livestock and Water resources- within which 61 activities may occur. Within each sector, the activities available for selection are determined by the combination of geographical region and climatic regime.

2.2 IMPACTS' ORDERING

Throughout the suite of models, primary and higher order impacts are presented by a combination of numerical notation and paragraph indents. In this system, the number signifies the level of impact, so 1. is a primary impact caused directly by the project, and 2. are the secondary impacts caused by a primary impact, and so on.

In reality, the number of higher-order impacts is potentially vast and the knowledge within the system is structured in order to permit realistic simulation of this process. However, when the system is in normal use, no more than five levels of impacts are presented to the user. It was decided to limit the search to five levels after considering the requirement to demonstrate the real complexity of environmental systems and the need to keep search times short. In order to present feedback within the system, and to prevent eternal looping, the word "loop" is entered at the end of any impact which has appeared further up the list. This signifies that the user should reexamine the list for the first occurence of the impact and consider the implications of the feedback.

3 SIMULATION RESULTS AND INTERPRTATION

In this section, the possibilities of development that are induced by the water transfer are analyzed in terms of environmental and socio-economic impacts on transfer and exporting regions. This can be very significant since the ultimate goal of the transfer is to stimulate production and regenerate the ecosystems.

In the following sections, the alternative development scenarios - Agriculture, Livestock breeding and Forestry- are split into main components or activities.

3.1 AGRICULTURE

The most severe impacts would follow the option of large scale irrigation. The situation in newly developed areas will evolve rapidly to show signs which at present are threatening the perimeters of the Senegal River Basin. In the following development we provide some general comments on the impacts which have been automatically retained by ECOZONE. It can happen that different primary impacts generate the same series of secondary impacts. In other circumstances, a primary impact that can be defined as a cause in a specific process is sometimes found as a fifth-degree impact or effect. In order to avoid lengthy explanations, we have grouped the impacts which present the same process of deterioration of a specific natural resource (soil, water, vegetation or health).

- **Increase in water abstraction/Reduced downstream flow**

  The new projects will be connected to the Diama storage reservoir on the Senegal River via Lac de Guiers. The Diama reservoir has enough capacity to paliate this impact since a constant flow of 200-300 m^3/s will be maintained in the river and will allow sufficient water to fill the lake.

  The reduction of water flow has already happen downstream from Diama dam; the revival of the hydrographic network would not substantially change the situation. Major impacts are related to the increase of salinity in the estuarine waters but any reliable data have not yet been captured.

- **Increased water-borne diseases and disease vector production**

  This aspect can be very serious for local communities survival and therefore for the future of agricultural development schemes given the example of the situation around Richard-Toll where bilharzia and malaria are endemic because of the rice and sugar schemes.

  Solutions proposed by Ecozone are of prime importance and in accordance with tohose given by the Senegal River basin Health Master Plan Study:

- Need for health management plans

- Installation of proper drainage/sewage systems

- Vector habitat control programmes

- **Waterlogging, salinisation and soil crusting**

  All of the processes produce the same negative impact:

- Waterlogging will decrease the aeration of root zone, reduce yields and cause financial losses which can turn the schemes into failure and abandonment

- Salinization would affect crops directly and reduce yields while crusting decreases infiltration and provoke waterlogging.

These processes have to be taken into account when rehabilitating aged perimeters by improving drainage systems.

- **Increase of potential crop production**

It can be a major source of conflict between economic goals and environmental management because it generally induces the massive use of inorganic fertilizers and pesticids, thus, generating excessive production costs. Pollution of aquifers and surface waters cause serious damage to human communities and wildlife. A thourough control of quantities and toxicity of products, and a surveillance of concentrations can help respect norms where biological fertilization methods cannot be applied.

- **Displacement of indigenous populations**

The issue relates directly to land property rights associated to large scale development projects. The experience in SRB has proven in Richard-Toll area, that severe dsruption of indigenous societies has occured. However, when the schemes are operated by farmers themselves, land conflicts diminish. New sources of conflicts or potential problems relate to the maintenance of common infrastructure like dykes and canals. If unresolved, the conflicts generate degradation processes (soil erosion and crusting) take over within a few years.

- **Reduced access to ressources for local people**

Beside income losses the diversion of needs toward other resources such as forests causes serioous environmental degradation in longer term with the depletion of water resources, heavy soil erosion and deforestation.

- **Microclimate modification**

Increase of pest will happen due to the shortenning of the dry season. The use of stronger pesticids in large quantities to respond to new diseases is foreseable when cultivation intensity tend to increase up to 200%.

3.2 LIVESTOCK

The development of livestock breeding was modelled by considering that various activities could take place at a time in the Ferlo which is the vocational livestock breeding region:

- Increase of stocking density and use of communal grazing land characterize the traditional fulani extensive herding
- Cattle ranching and rangeland grazing correspond to government-sponsored activities (e.g. Ranch de Doli).

Since all types of activities are likely to occur, the range of modellized impacts seems to be realistic. We have further discarded dairy production activities on the basis of the failure of past dairy schemes for anthropological reason (resistance of fulani herders to the structuration of the dairy circuit).

- **Increased pressure on grazing land**

All year round water availability would disturb the transhumance system which is an adaptation to the constraints of Sahelian systems. It will cause a rapid rise of stocking density. The consequences would be quantitative and qualitative depletion of vegetation and fodder. Heavy erosion, soil compaction and in-channel sedimentation will follow causing a disequilibrium of the ecosystems.

- **Livestoock diseases**

Increasing stocking density would favor transmission of pests and cattle morbidity. Meat consumption within local household would decrease. Hoowever, the traditional nutrition system does not integrate much meat and the repercussions would be of minor importance compared to the threat from pesticids.

3.3 FORESTRY

Two types of activities were chosen to reflect the realm of forestry in Senegal:

- Plantation of exotic trees such as Eucalyptus for timber and fuelwood production

- Plantation or regeneration of native tree species in social forestry with the aim of protection and rehabilitation of traditional production systems.

The timber production will increase to satisfactory levels, and subsequently, the pressure on adjacent forests would decrease. However, the quality of wood products is an important factor of reforestation operations. The product has to be culturally adequate otherwise there will be resistance and the commercial value would drop.

Rehabilitated marginal land is generally reconquered by agricultural activities. The increase of the value of land will create conflicts; new possession would push many people out of the area causing social unrest. Some of the actual forestry projects are plagued by the land rights issue and carefull planning of land allocation can help avoid the problems.

Report of a Search for the Environmental Impacts of Natural Resource Projects using ECOZONE

Date: 01/04/1995
Time: 16:46:20

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ECOZONE:  Lowland Arid
Sector:        Agriculture
Activity: large scale irrigation,

 1,
 1,increase in water abstraction
    2,reduced aquifer water supply
    2,reduced groundwater level
       3,altered vegetation/habitat
       3,increased pollutant concentration
       3,land subsidence
          4,damage to infrastructure/roads
    2,reduced riverine forest
       3,reduced forest production
          4,irregular/seasonal stream flow
             5,irregular downstream water flow
             5,increased flooding of downstream areas
          4,reduced evapo-transpiration loss
             5,increased run-off
          4,fuelwood shortage
             5,burning of dung
             5,burning of agricultural waste
       3,increased soil erosion
          4,increased sedimentation of water channels
             5,increased water turbidity
             5,increased lake siltation
             5,reduced riverine/lacustrine fish produ
             5,reduced streambed erosion
             5,increased waterway bottom rise
          4,increased suspended solids in sea
             5,reduced coral growth
             5,reduced photosynthesis
          4,increased fertility downstream riverbeds
             5,increased fish production
    2,increased salt water intrusion of soil and grou
       3,reduced yields
          4,reduced income
             5,decreased investment in cash crops
 1,reduced downstream water flow
    2,increased salt water intrusion up river
       3,altered species distribution/diversity
          4,altered ecosystem stability
    2,disruption of riverine fisheries
    2,increased salt water intrusion of soil and grou
       3,reduced yields
          4,reduced income
             5,decreased investment in cash crops
    2,moderation of downstream flooding
       3,reduced floodplain fisheries production
       3,disrupted traditional recession agriculture
          4,increased inorganic fertiliser use
             5,reduced soil organic matter
             5,reduced fallow period
             5,reduced manuring
             5,increased yields
             5,leaching/run-off into water
          4,irrigation
             5,(choose from activities in Agriculture
          4,reduced soil organic matter
             5,reduced soil fertility
             5,loss of soil structure
             5,loss of soil water retention
             5,soil compaction
          4,reduced fallow period
             5,(choose from activities in Agriculture
       3,altered natural vegetation
          4,reduced wildlife habitat
             5,loss of endangered species
             5,displacement of wildlife
```

```
         4,disrupted grazing patterns
1,increased water-borne diseases
   2,need for health management
   2,need for drainage/sewage system
1,increased disease vector production
   2,need for health management
   2,need for vector habitat control
1,waterlogging of soil
   2,poor aeration of root zone
      3,reduced yields
         4,reduced income
            5,decreased investment in cash crops
1,increased potential crop production
   2,increased inorganic fertiliser use
      3,reduced soil organic matter
         4,reduced soil fertility
            5,reduced yields
            5,land degradation/abandonment
         4,loss of soil structure
            5,increased soil erosion
         4,loss of soil water retention
         4,soil compaction
            5,reduced water infiltration
            5,poor root penetration
            5,poor aeration of root zone
      3,reduced fallow period
         4,(choose from activities in Agriculture)
      3,reduced manuring
         4,reduced soil organic matter,(loop)
         4,reduced annual production of pasture vege
            5,reduced livestock production
      3,leaching/run-off into water
         4,eutrophication
            5,reduced water quality
            5,algal bloom
      3,increased yields
         4,excess supply
            5,reduced crop market value
         4,increased food supply
            5,improved local/household nutrition
         4,increased income
   2,use of herbicides and pesticides
      3,death of non-target species
         4,reduced pollination
         4,reduced natural pest control
            5,reduced yields
      3,persistence in food chain
         4,death of organisms at higher trophic leve
         4,unpredicted ecological effects
         4,health hazard
      3,development of resistance in pests
         4,increased agricultural pests/diseases
            5,use of herbicides and pesticides,(loop
      3,increased costs of production
      3,pollution of soil
         4,pollution of surface and groundwater
            5,reduced fish production
            5,fish unsafe to eat
            5,contaminated drinking water supply
      3,risk of spray drift
         4,damage to adjacent vegetation/habitats
         4,danger to animals/people
         4,death of non-target species,(loop)
1,salinisation of soil
   2,reduced yields
      3,reduced income
         4,decreased investment in cash crops
1,crusting of exposed topsoil
   2,reduced water infiltration
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```
        3,reduced soil moisture
           4,reduced yields
              5,reduced income
        3,reduced groundwater recharge
           4,reduced groundwater level
              5,altered vegetation/habitat
              5,increased pollutant concentration
              5,land subsidence
        3,increased run-off
           4,increased soil erosion
              5,increased sedimentation of water chann
              5,increased suspended solids in sea
              5,increased fertility downstream riverbe
           4,irregular/seasonal stream flow
              5,irregular downstream water flow
              5,increased flooding of downstream areas
           4,flash flooding
           4,reduced soil organic matter
              5,reduced soil fertility
              5,loss of soil structure
              5,loss of soil water retention
              5,soil compaction
  1,displacement of indigenous population
     2,loss of indigenous knowledge
     2,severe disruption of indigenous society
        3,malnutrition
        3,introduction of new diseases
           4,decimation of population
        3,cultural disintegration
     2,inadapted cultural practices
        3,increased soil erosion
           4,increased sedimentation of water channels
              5,increased water turbidity
              5,increased lake siltation
              5,reduced riverine/lacustrine fish produ
              5,reduced streambed erosion
              5,increased waterway bottom rise
           4,increased suspended solids in sea
              5,reduced coral growth
              5,reduced photosynthesis
           4,increased fertility downstream riverbeds
              5,increased fish production
        3,reduced fallow period
           4,(choose from activities in Agriculture)
        3,crusting of exposed topsoil
           4,reduced water infiltration
              5,reduced soil moisture
              5,reduced groundwater recharge
              5,increased run-off
  1,more humid micro-climate
     2,reduced dry season die-back
        3,increased agricultural pests/diseases
           4,use of herbicides and pesticides
              5,death of non-target species
              5,persistence in food chain
              5,development of resistance in pests
              5,increased costs of production
              5,pollution of soil
              5,risk of spray drift
              5,danger to health of operatives
              5,biocide residue on crops
              5,disposal problems of waste and packagi
              5,increased yields
  1,increased cultivation area
     2,(choose from activities in Agriculture)
  1,increased cultivation intensity
     2,(choose from activities in Agriculture sector)
  1,reduced water supply for other uses
  1,increased year round vegetation cover
```

```
      2,reduced soil exposure
         3,reduced soil erosion
            4,maintained crop production
   1,reduced access to resources for local people
      2,altered local/household economy
      2,increased degradation of adjacent forest
         3,reduced forest production
            4,irregular/seasonal stream flow
               5,irregular downstream water flow
               5,increased flooding of downstream areas
            4,reduced evapo-transpiration loss
               5,increased run-off
            4,fuelwood shortage
               5,burning of dung
               5,burning of agricultural waste
      2,fodder shortage for landless livestock farmers
      2,increased use of marginal/sloping land
   1,reuse of wastewater
```

ECOZONE: Lowland Arid
Sector: Livestock
Activity: increased stocking density, use of common land for grazing, cattle ranching, rangeland grazing,

1,increased pressure on common/grazing land
    2,increased overgrazing
        3,reduced species diversity of pasture vegetat
            4,reduced palatability of pasture
                5,reduced livestock production
        3,reduced annual production of pasture vegetat
            4,reduced livestock production
                5,reduced local/household nutrition
        3,increased soil erosion
            4,increased sedimentation of water channels
                5,increased water turbidity
                5,increased lake siltation
                5,reduced riverine/lacustrine fish produ
                5,reduced streambed erosion
                5,increased waterway bottom rise
            4,increased suspended solids in sea
                5,reduced coral growth
                5,reduced photosynthesis
            4,increased fertility downstream riverbeds
                5,increased fish production
        3,soil compaction
            4,reduced water infiltration
                5,reduced soil moisture
                5,reduced groundwater recharge
                5,increased run-off
            4,poor root penetration
                5,reduced yields
            4,poor aeration of root zone
                5,reduced yields
    2,fodder shortage
        3,increased degradation of adjacent forest
            4,reduced forest production
                5,irregular/seasonal stream flow
                5,reduced evapo-transpiration loss
                5,fuelwood shortage
1,increased livestock disease
    2,reduced livestock production
        3,reduced local/household nutrition
    2,use of herbicides and pesticides
        3,death of non-target species
            4,reduced pollination
            4,reduced natural pest control
                5,reduced yields
        3,persistence in food chain
            4,death of organisms at higher trophic leve
            4,unpredicted ecological effects
            4,health hazard
        3,development of resistance in pests
            4,increased agricultural pests/diseases
                5,use of herbicides and pesticides,(loop
        3,increased costs of production
        3,pollution of soil
            4,pollution of surface and groundwater
                5,reduced fish production
                5,fish unsafe to eat
                5,contaminated drinking water supply
        3,risk of spray drift
            4,damage to adjacent vegetation/habitats
            4,danger to animals/people
            4,death of non-target species,(loop)
1,soil compaction
    2,reduced water infiltration
        3,reduced soil moisture
            4,reduced yields

```
            5,reduced income
        3,reduced groundwater recharge
            4,reduced groundwater level
                5,altered vegetation/habitat
                5,increased pollutant concentration
                5,land subsidence
        3,increased run-off
            4,increased soil erosion
                5,increased sedimentation of water chann
                5,increased suspended solids in sea
                5,increased fertility downstream riverbe
            4,irregular/seasonal stream flow
                5,irregular downstream water flow
                5,increased flooding of downstream areas
            4,flash flooding
            4,reduced soil organic matter
                5,reduced soil fertility
                5,loss of soil structure
                5,loss of soil water retention
                5,soil compaction,(loop)
    2,poor root penetration
        3,reduced yields,(loop)
    2,poor aeration of root zone
1,reduced annual production of pasture vegetation
    2,reduced livestock production
        3,reduced local/household nutrition
1,reduced species diversity of pasture vegetation
    2,reduced palatability of pasture
        3,reduced livestock production
            4,reduced local/household nutrition
1,increased competition for vegetation/water
    2,increased overgrazing
        3,reduced species diversity of pasture vegetat
            4,reduced palatability of pasture
                5,reduced livestock production
        3,reduced annual production of pasture vegetat
            4,reduced livestock production
                5,reduced local/household nutrition
        3,increased soil erosion
            4,increased sedimentation of water channels
                5,increased water turbidity
                5,increased lake siltation
                5,reduced riverine/lacustrine fish produ
                5,reduced streambed erosion
                5,increased waterway bottom rise
            4,increased suspended solids in sea
                5,reduced coral growth
                5,reduced photosynthesis
            4,increased fertility downstream riverbeds
                5,increased fish production
        3,soil compaction
            4,reduced water infiltration
                5,reduced soil moisture
                5,reduced groundwater recharge
                5,increased run-off
            4,poor root penetration
                5,reduced yields
            4,poor aeration of root zone
                5,reduced yields
    2,reduced wildlife habitat
        3,loss of endangered species
            4,reduced biodiversity
                5,genetic erosion
        3,displacement of wildlife
            4,damage to crops
1,increased livestock production
    2,increased food supply
        3,improved local/household nutrition
            4,improved health
```

Report of a Search for the Environmental Impacts of Natural Resource Projects using ECOZONE

Date: 01/04/1995
Time: 17:06:28

ECOZONE: Lowland Arid
Sector: Forestry
Activity: plantation of exotic tree species, plantation of native tree species,

```
1,risk of unpredicted ecological effects
1,increased timber production
  2,reduced pressure on adjacent forest
1,rehabilitation of marginal/degraded land
  2,increased potential crop production
    3,increased inorganic fertiliser use
      4,reduced soil organic matter
        5,reduced soil fertility
        5,loss of soil structure
        5,loss of soil water retention
        5,soil compaction
      4,reduced fallow period
        5,(choose from activities in Agriculture
      4,reduced manuring
        5,reduced soil organic matter,(loop)
        5,reduced soil fertility
        5,reduced annual production of pasture v
      4,leaching/run-off into water
        5,eutrophication
      4,increased yields
        5,excess supply
        5,increased food supply
        5,increased income
    3,use of herbicides and pesticides
      4,death of non-target species
        5,reduced pollination
        5,reduced natural pest control
      4,persistence in food chain
        5,death of organisms at higher trophic l
        5,unpredicted ecological effects
        5,health hazard
      4,development of resistance in pests
        5,increased agricultural pests/diseases
      4,increased costs of production
      4,pollution of soil
        5,pollution of surface and groundwater
      4,risk of spray drift
        5,damage to adjacent vegetation/habitats
        5,danger to animals/people
        5,death of non-target species,(loop)
1,increased evapo-transpiration loss
  2,reduced soil moisture
    3,reduced yields
      4,reduced income
        5,decreased investment in cash crops
  2,reduced groundwater level
    3,altered vegetation/habitat
    3,increased pollutant concentration
    3,land subsidence
      4,damage to infrastructure/roads
  2,irregular/seasonal stream flow
    3,irregular downstream water flow
    3,increased flooding of downstream areas
      4,increased vulnerability of life/economy
      4,restored soil moisture
      4,increased silt deposition
        5,replenishes floodplain soil
1,increased potential growth rates
1,socio-cultural resistance to use
1,increased employment
1,influx of labourers
  2,introduction of new diseases
    3,decimation of population
1,restriction of traditional rights of land use
```