

Assessment and Provision of Environmental Flows in Mediterranean Watercourses

- Basic Concepts, Methodologies and Emerging Practice

Mediterranean Case Study

Review of certain basic elements for the assessment of environmental flows in the Lower Moulouya

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I. CONTEXT OF THE LOWER MOULOUYA:

Geographical Location:

With a surface area of 54,500 km², the Moulouya watershed is the largest river basin of Morocco and of the non-Saharan river systems of Northern Africa. On a morphological level with regard to the upriver area, the River Moulouya flows through a large expanse of plains, whereas the mountain regions furnish water and sediments via its numerous tributaries. Upon leaving the gorges cut into the calcareous hillsides, the Moulouya meanders into a larger plain. It covers a distance of 75 km to drain into the Mediterranean amidst a coastal plain consisting of its delta, 4 km wide and 20 km long.

The mouth of the river and its marsh complex constitute a Site of Biological and Ecological Interest (Site d'intérêt biologique et écologique, or SIBE) of approximately 3,000 hectares. It is a refuge for numerous birds of international and national interest, as well as the habitat of privileged and diversified fauna and plant formations that are exceptional for Morocco.

The climate of the Moulouya Basin is of a semi-arid Mediterranean type, with markedly irregular precipitations. The average annual precipitation is estimated at 1,400 million m³ (General Directorate of Hydraulic Affairs, 1971), with an annual pluviometric index ranging from 230 to 380 mm. The run-off rate is estimated at 16 mm with an average rainfall of 300 mm.

The population of the Moulouya Basin was approximately 2.2 million inhabitants in 1994. It is predominantly rural, with a clear tendency towards exodus to urban areas due to the weakness of the structures maintaining people in the rural milieu and an increased migratory flux. Trends indicate that by 2020, as compared to 1985, there will be a pronounced increase in population, especially in the region of Lower Moulouya (x 2.13).

Socio-economic activities are predominantly in the agro-pastoral sector and the industrial sector, concentrated in the northern areas.

National policy on water issues and administrative framework:

Several administrations are involved in water issues on a national level in general and on the Moulouya Basin level in particular: the General Directorate of Hydraulic Affairs (DGH), the National Office of Potable Water, the Department of Water, Forestry and the Struggle Against Desertification, the Office of Agricultural Development of Moulouya, the State Secretariat for the Environment and the State Secretariat for Water Affairs. On an inter-sectoral level, the Water and Climate Authority formulates the general orientation of national water policy, whereas the Moulouya Water Basin Agency organises and manages the water at the Moulouya Basin level.

With regard to legislation, Act 10-95 on water and its principal stipulations on application allow a more efficient, decentralised management of water resources that is jointly established at all levels by the administration, users and elected politicians. It is thanks to this law that the basin agencies were created in order to manage the water coherently, taking into consideration the entirety of the watershed.

II- DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES

The Moulouya Basin is in a situation of structural water deficit. The highly irregular precipitation and run-off rates limit the possibilities of rain-fed agriculture and of the potable and industrial water supply, making it necessary to regulate water flow by the construction of the Mohamed V-Mechra Homadi hydraulic complex and annexed constructions.

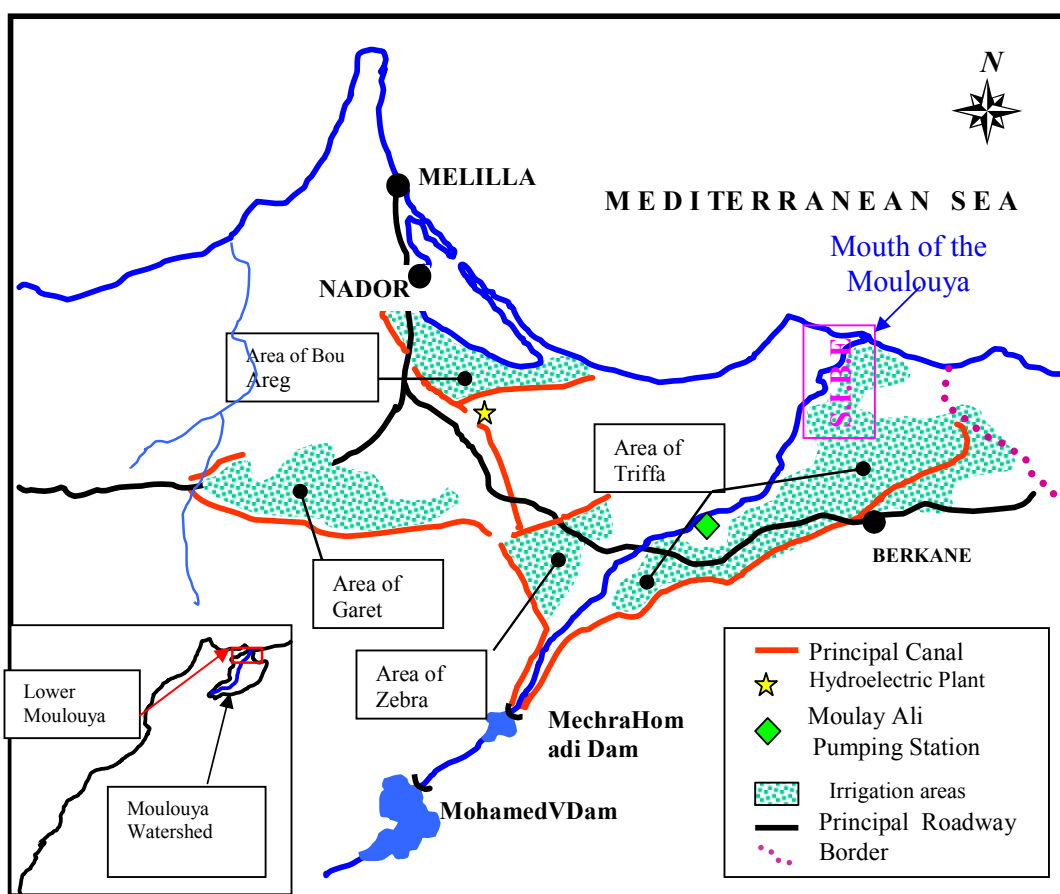


Fig. 1: Lower Moulouya – Location and Facilities

1-Mobilisation of surface water:

The principal surface water mobilisation works existing in the Moulouya watershed are represented in Table 1.

Existing Hydraulic Works	Usage
Hydraulic Complex of the Mechra Homadi Dam (1957) and Mohamed V Dam (1967) on the Moulouya	- Irrigation of the Lower Moulouya plains (524 Mm ³ /year) - Potable water supply to the cities of Berkane, Nador and neighbouring areas (30 Mm ³ /year) - Production of electrical energy (29MW)
Hassan II Dam on the Za Wadi (1995)	- Additional supplies for irrigation along the Za Wadi (34 Mm ³ /year) - Volume reserved for reinforcement of the potable water supply for the cities of Oujda, Laayoune and Taourirt (38 Mm ³ /year)
Hillside dams and lakes	Water supply for livestock and protection of certain municipalities against floods
Moulay Ali Pumping Station (1993)	Additional water supplies for irrigation on the Triffa Plain (Lower Moulouya)

Table 1: Hydraulic works existing in the Moulouya River Basin (Naïmi, 2002)

The Mohamed V Dam is the largest on the Moulouya. It is located approximately 75 km from the mouth and was inaugurated in 1967. It ensures the irrigation of the Lower Moulouya plains through water volumes discharged and diverted at the afterbay dam of Mechra Homadi, from which 2 major

canals run: the Triffa Canal, on the right bank; and the left bank canal that supplies the areas of Zebra, Garet and Bou Areg (Fig. 1).

The water discharge decisions are made in the first place to evacuate sharp rises in the water level in order to ensure dam safety, as well as to meet irrigation needs according to the season, the volume available at the dam and the agricultural year.

The Mohamed V Dam is likewise equipped with a hydroelectric power station that uses irrigation water and part of the overflow.

2- Hydrology of the Moulouya downriver of the dams:

- Below the Mechra Homadi Dam, the Moulouya is essentially supplied by resurgences occurring in the gorges. The inauguration of the Moulay Ali Pumping Station in 1993 aimed at extracting 3 to 4 m³/s to supply the irrigation channels of the Triffa plain with additional resources. Nevertheless, the elevated cost of this operation as well as the disturbances caused to the PMH (small and medium-sized hydraulic) irrigations limited the exploitation of these resurgences. We can consider that these resurgences continue to play their role in environmental flow today by attenuating the effects of water extraction caused by all of these facilities. Downriver of Moulay Ali, there are additional water supplies estimated at approximately 2 m³/s, yet they are more or less brackish as they originate from the drainage of irrigated land.

- Farther downstream, the Cherraa Wadi, whose tributary, the Zegzel Wadi, drains the calcareous mountains of Béni Snassen, flows into the right bank of the Moulouya. This river has an average annual flow of 135 Mm³/year, primarily consisting of swells, as the regular flow hardly surpasses 100 l/s. Nevertheless, the Cherraa Wadi is diverted for irrigation and is often dry well before reaching the main course of the Moulouya.

3- Groundwater:

With regard to the Lower Moulouya and the region of Nador, the hydro-geological basin comprises:

- the Triffa water table, in which 3,000 wells are currently used as a complement to surface water for irrigation. In any case, the major problem is the salification of this water table, specifically in lower areas. In the entire water table, only one zone covering a third of the surface area is suitable for irrigation (varying salinity ranging from 0.5 to 1.5 g/l).

- the Béni Snassen water table constitutes an important aquifer comprised of the dolomitic limestone of Lias. Springs are used for irrigation and wells for potable water supply.

- the Garet and Bou Areg water tables are fed by rainwater and the runoff from irrigation. The chemical quality is mediocre, as global mineralisation ranges from 2 to 16 g/l.

The total volume of groundwater from the different aquifers currently in use is estimated at approximately 230 Mm³, 2/3 of which are employed for irrigation.

3- Current appraisal of water use:

The water resources mobilised represent 1,122 Mm³/year, whereas the demand is 1,222 Mm³/year. The mobilised water is principally consumed by agriculture (95%) and domestic use. This deficit of 100 Mm³/year puts the Moulouya Basin in a situation of water shortage.

The political priorities of water management, particularly in periods of drought, aim first and foremost to satisfy the population's demand for potable and agricultural water. At the beginning of each agricultural year, the water administrators and the farmers attempt to reach a consensus for the allocation of flows, but the shortage of the resource often generates conflicts among the different users.

The ecological conservation of the wetland downriver of the dams has been absent from these policies to date. It is only recently, with its SIBE status and the MedWetCoast project, that an interest in protecting these areas has been recognised.

III- CONSTRAINTS ON THE USE OF WATER RESOURCES

The regulation of the Moulouya Wadi has certainly provided many advantages for the socio-economic development of the region, yet a certain number of constraints prevent the normal pursuit of the water management strategy and lead decision-makers to seek other solutions or adapt their management programme. Among these constraints are:

- The quick silting up of the dam reservoirs:

The dams of Mechra Homadi and Mohamed V have been identified by the Ministry of Public Works (1996) as being at a critical stage with regard to the volume of silting in the case of the former dam and the life of the latter dam.

The volume of the Mechra Homadi dam has gone from its initial 42 Mm³ to only 8 Mm³. It was the object of a silt clearance project in 1995, which aimed to recover 3 Mm³ of lost volume.

The rapid silting up of the Mohamed V reservoir is another worrisome phenomenon, as the volume of the reservoir, originally 726 Mm³, is now nothing more than about 200 Mm³, that is, a loss of nearly 73% of the dam's initial capacity. According to the estimates of the National Plan for Watershed Management (1994), the useful capacity of the reservoir will be reduced to 0 in 2020, and completely filled in by 2030, 64 years after its inauguration. Snoussi et al. (2002) estimated the life of the dam at only 59 years.

According to the Water, Forestry and Soil Conservation Administration (1994), the specific deterioration is estimated at approximately 240 t/km²/year based on inflow of solid matter and at 330 t/km²/year based on the actual silting up of the dam. The significance of erosion is directly linked to the geological and morphological nature of the land, but also to the rapid erosion of the plant covering, namely the decline of the esparto grass prairies. The areas of erosion cover approximately 1/5 of the Basin. It seems that the fundamental measures to protect the watershed would be mechanical action and not biological intervention. The construction of more dams upriver would contribute to slowing the silting up process of the Mohamed V reservoir.

Exceptional floods and droughts:

In the Moulouya River Basin, rainy weather is rare, but sometimes the precipitation in April-May and October-November can be exceptionally strong and generalised throughout the basin area. This is the case of the floods of May 1963 (the highest), April 1975 and November 1993. The one in 1963 reached a speed of 7,200 m³/s and caused not only a significant change in the morphology of the lower Moulouya and its estuary, but also serious damage. The flood waters are drained via the discharge mechanisms of the Mohamed V and Mechra Homadi dams. In any case, their ceilings being 6,000 m³/s, these mechanisms have been found to be under-dimensioned, which makes the dams less safe and more fragile. According to the Master Plan, the construction of more dams upriver or the increase of the drainage capacity of the 2 existing dams to 3,000 m³/s (too costly) would be potential solutions. Moreover, droughts severe in both intensity and duration have ravaged the whole of Morocco during the past two decades. In the Moulouya Basin, the periods of drought, lasting from 2 to 5 years on average, have severely affected agriculture, livestock breeding, the supply of potable water and hydroelectric production.

Deterioration of water quality:

The growth of urban and industrial activities generating liquid and solid wastes, as well as the intensive use of fertilisers and plant protection products in agriculture in the Moulouya Basin have inevitably entailed the deterioration of the quality of water resources. The monitoring network installed by the General Directorate of Hydraulic Affairs throughout the Basin shows that certain water tables (Angad, Triffas) have a significant degree of salinity and nitrate levels. The area of the estuary has revealed the presence of heavy metals (particularly Zn and Cd) in the water, sediments and elvers (Rahhou, 1995).

Some effort in water protection is thus called for in order to limit negative consequences on the environment and populations.

III- TOOLS AND METHODS THAT COULD BE USED TO EVALUATE THE ENVIRONMENTAL FLOWS OF THE LOWER MOULOUYA:

The Moulouya Basin has not yet been the object of an integrated study allowing the definition of the conditions required for the allocation of an environmental flow. Nevertheless, a certain number of hydrological, sedimentological, morphological, environmental, ecological and socio-economic studies, each with specific objectives, have been carried out separately on this Basin. The most important of these studies, though it is not up to date, is the one that has allowed the Water Research and Planning

Authority (DRPE) to establish a Master Plan for Water Management in the Moulouya Basin (CSE, 1992). The principal results of these studies are as follows:

1- Establishment of water need scenarios and a management plan for the future:

On the basis of current water demand projections, the DRPE has established a programme for water mobilisation works until 2020, and proposes a management plan in order to meet the increasing pressure on the already limited water resources of the Moulouya Basin. The principal objectives of this management plan are:

- the maximum mobilisation of water resources in order to meet the demand for potable, industrial and irrigation water;
- the protection of the Mohamed V Dam against silting;
- and the capping of the maximum flood probability at 6,000 m³ /s.

The resource-needs balance scenarios consider two options: a plan without a new dam, and a plan with the construction of dams of local interest and dams of regional interest.

The first scenario results in a deficit of approximately 200 Mm³/year, whereas the scenario with construction of dams results in a surplus of approximately 30 Mm³/year with a use rate of the lower Moulouya of 81%. In any case, the water demand forecasts in the Moulouya Master Plan (1992) are somewhat outdated. The report from 1997 on the water sector study carried out by the Ministry of Public Works updated the data, integrating the most recent forecasts (Table 2).

Resources/Needs	Regulated volume in the system (Mm ³ /year)
Mobilisation of surface water	
Existing regulating dams	480
Dams projected for construction by 2020	355
Moulay Ali Pumping Station	95
Total surface water	930
Exploitation of subsoil water	500 Mm ³ /year
Total Resources	1430 Mm³/year
Demand for potable and industrial water	148 Mm ³ /year
Demand for irrigation water	1,458 Mm ³ /year
Total demand	1,606 Mm³/year
Balance foreseen for the year 2020	- 176 Mm³/year

Table 2: Resources-Needs Balance foreseen for 2020 in the Moulouya River Basin (Ministry of Public Works, 1996)

It appears, therefore, that despite the construction of projected dams, the water resources available in 2020 will not be able to fully meet the water demand. Furthermore, the deficit obtained of 176 Mm³/year is an underestimation, as it does not take into account the reduction of water resources due to global warming, estimated in Morocco at approximately 15% by 2020. (MATUHE, 2001).

On the environmental level, the analysis of the impacts caused by the construction of the various dams presented in the Master Plan considers:

- negative effects only with regard to the surface areas and habitats that would be flooded by the dams. The ecosystems and populations at risk downriver of the dams were not considered at all in the environmental impact study; and
- the probable positive consequences on the quality of water of the Moulouya and its tributaries, based on a foreseen sustained low water mark that could dilute any possible pollution.

Now, with its SIBE status and the MedWetCoast project diagnosis, the downriver area could be expected to be included as a whole in the management strategies for natural resources in general, and for water resources in particular in the basin.

2- Management models proposed for the Lower Moulouya:

The Mohamed V Dam has been the object of a study on water management in real time, during which tools to aid in decision-making were developed (Tabit, 1993). These tools have been installed at the offices of the Water Research and Planning Authority.

Two strategies were taken into account: the "normal" strategy optimised on the long term and the "drought" strategy, optimised for a situation of persistent shortage.

The determination of allocations on the medium term based on economic value were done using the LORIT dynamic programming model and taking into consideration both the physical limitations of the surface and underground reservoirs, and water quality restraints.

As a result of the studies, two decision-making aids were proposed:

- the aid for defining irrigation programmes on 1st October and 1st March;
- the decision-making aid for water discharge from dams and pumping stations on a monthly and daily basis for the agriculture programme instituted, considering the evolution of the hydrological situation and the water stock in the Mohamed V Dam reservoir.

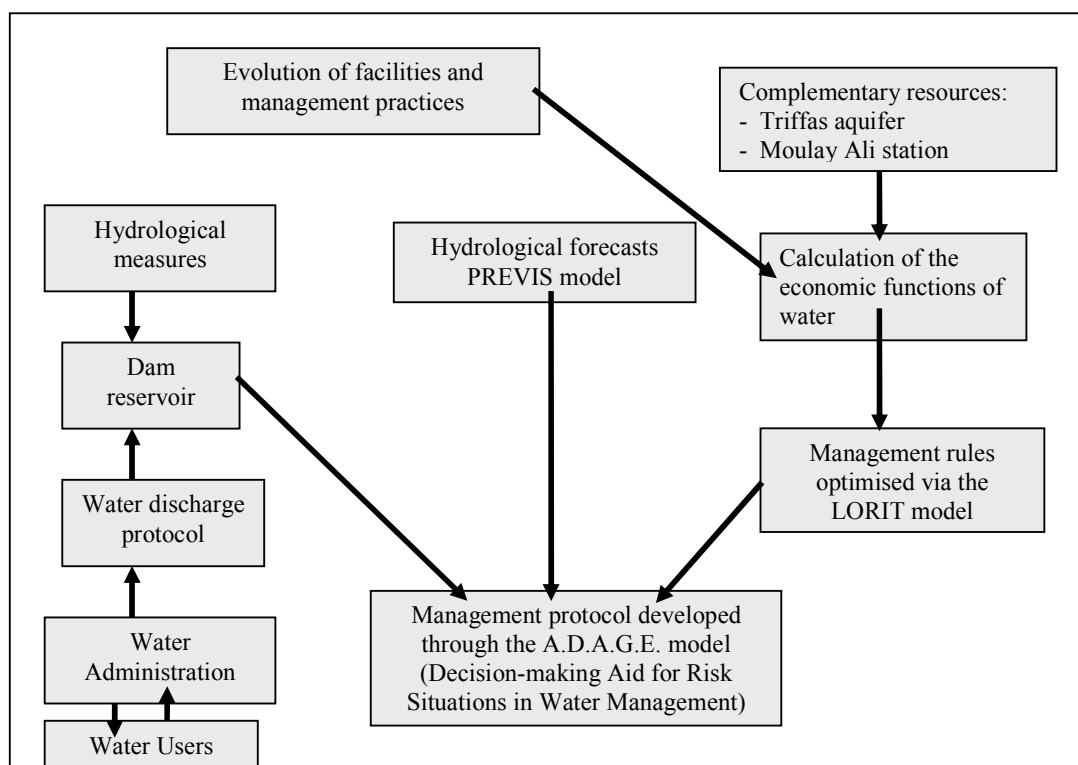


Fig. 2: Tools for water resource management for the Lower Moulouya (Tabit, 1993)

This study nonetheless raises the matter of the difficulty of implementing such a management system due to the complexity of the problems and uncertainties with regard to organisation, economy, knowledge of subterranean water resources, agriculture, water quality, users' support, etc.

Although it only takes into account the dam supply flows with user exploitation objectives and makes no mention whatsoever of the minimum ecological flow, this model will nonetheless prove useful for the following steps in the evaluation of flows from a more global viewpoint, as it presents the water discharge protocol as depending on a certain number of conditions.

3- Study of the reduction of liquid and solid matter inflow and its impact on the lower course of the Moulouya (Snoussi et al. 2002):

This study constitutes another contribution to a global understanding of the environmental flows of the Moulouya. It effectively contributes to improve knowledge on disruptions of the upriver-downriver

flow continuum for the Moulouya after construction of the dams. It is based on the data on liquid and solid matter flows available from the General Directorate of Hydraulic Affairs.

Stations	Liquid Flows (Mm ³ /year)	Solid Flows (10 ³ t/year)
Upriver of the dams (Melg El Ouidane Station)	941	8,600
Downriver of the dams (Saf Saf Station)	317*	500*
Rate of reduction between the upriver of dam and downriver of dam sectors	66%	93%

* These values do not take into account dam discharges, which are highly variable and depend on a great deal of factors.

Table 3: Liquid and solid matter flows of the Moulouya upriver and downriver of dams.

Despite the absence of data taken over long periods for certain stations downriver of the dams, the evaluation of the current situation (Table 3) shows that the liquid flows of the Moulouya have undergone a reduction of 66% downriver of the dams. If we deduct the volume used for irrigation (25 Mm³), we obtain a volume of water outflow to the sea of 292 Mm³, that is 31% of the total volume of the Moulouya.

With regard to solid matter flow, if the dam releases are not taken into account, the reduction of flows downriver of dams is estimated at 93%, a value similar to the trapping efficiency of the reservoir as estimated by Snoussi et al. (2002), also at 93%. This means that only 7 % of the solid matter flow of the Moulouya currently reaches the sea.

The construction of the Mohamed V and Mechra Homadi dams on the Moulouya has undeniably had a very positive impact with regard to the mobilisation and use of water resources, improving the standard of living of the region's population. These multiple use dams (water for drinking and industrial use, irrigation, energy) also serve to cap floods. Nonetheless, there have also been negative impacts on both the environmental and socio-economic levels for the downstream ecosystems.

Environmental Impacts

- Change in morphology of the lower course of the Moulouya

The study of the historical evolution of the lower course of the Moulouya and the coastline via analysis of aerial photographs and satellite images (Zourarah, 1995; Boumeaza, 2002; Imassi and Snoussi, 2003) has shown that, over more than half a century, the lower course of the Moulouya and its delta have undergone significant changes principally connected to the modification of the amount of water and sediment flows from the watershed. The latter are conditioned, on the one hand, by climatic phenomena and, on the other, by the structures (dams, canals, etc.) constructed within the watershed. Indeed, after the inauguration of the dams and the drastic reduction in flows, especially of sediments, the coastal morphology has reacted by making remarkable readjustments that translate into areas of erosion and areas of sedimentation. In general, it is evident that the delta shows a sharp retreat estimated at an average of 10m/year and that the Moulouya is currently cutting into the lowest terrace that it had built up before the installation of the dams.

- Salification of waters:

- Surface water:

Upriver of the Mohamed V dam, the waters of the Moulouya and its tributaries are generally of good quality. The water in the Mohamed V reservoir has a salinity level of some 1 g/l. This level increases progressively downriver of Mechra Homadi to 1.7 g/l, and rising to 2.6 g/l, for a basic flow that grows from 4 m³/s below the gorges to 6 m³/s at the mouth. The Moulay Ali Pumping Station has equally caused an increase in the salinity of the waters in the Lower Moulouya. In 1996, the salinity of surface waters ranged from 1.12 to 3.74 g/l (Benkaddour, 1997).

To this must be added the increased intrusion of marine water further upriver after the reduction of freshwater inflow.

- **Groundwater:**

Indirectly, the construction of the dams and the consequent development of agriculture in Lower Moulouya have undeniably had a detrimental effect on the quality of the groundwater in the plains of Triffa, Zebra, Garet and Bou Areg, where the water's salinity levels are sometimes very high. Apparently in 1996, $\frac{3}{4}$ of the Triffa groundwater were considered saline and unsuitable for irrigation (Benkaddour, 1997). The evolution of this salification process depends on climatic phenomenon and the use of the groundwater by private pumping stations. To fight against the increased salinity of the soil in irrigation areas, drainage works have been undertaken whose effect could be reinforced by rationalising the pumping of underground water for irrigation.

The pollution of the water table by fertilisers and pesticides is not yet very significant. According to the Water Authority (1990) and Benkaddour (1997), only 2 to 3% of wells have nitrate levels higher than the limit of 50 mg/l established as a European standard.

Socio-economic Impacts:

The silting up of the Mohamed V Dam has caused significant losses, namely: a loss of agricultural production due to the abandonment of flooded or overly saline land, the proletarianization of small farm operators, loss of employment and decreased energy production. According to the Ministry of Agriculture and Agricultural Development (1997), by 2030, the total economic loss in agricultural production (70,000 hectares) will be 740 million dirhams and the loss in electrical energy at 300 million KWh will be 210 million dirhams. In total, the economic losses due to the silting up of the Mohamed V Dam are estimated at 950 million dirhams by the year 2030. An economic evaluation of the costs of erosion both upriver and downriver of the dam (MAMVA, 1995) has revealed that, in contrast to other Moroccan river basins, the Moulouya Basin shows losses downriver of the dam (1,185 million dirhams) higher than those upriver (630 million dirhams).

The loss of or decrease in ecological values and functions of the wetlands downriver of the dams, though more difficult to quantify, has been evaluated within the framework of the MedWetCoast Project (Khattabi, 2002).

4- Diagnosis for the management of the wetland area of the Moulouya estuary (MedWetCoast Project):

To date, the only study that has looked into the problem of evaluating the state of the wetlands downriver of the dams has been carried out as part of the MedWetCoast-Morocco Project (2003), which covers the SIBE of the Moulouya estuary. This project, whose principal objective is the conservation of the wetland and coastal ecosystems of the Moulouya, could constitute an interesting initiative for a global debate on the conditions required for environmental flows.

The analysis of the current state of the coastal wetland area of the Moulouya, carried out by a multidisciplinary team as part of the MedWetCoast Project (Dakki et al., 2003), has revealed a certain number of dysfunctions and threats to this site. According to this study, it seems that the hydrological disruptions are the principal direct causes of these dysfunctions. In effect, this site has had little loss of habitats but has undergone serious modifications with regard to the nature and relative extent of these habitats, on the one hand due to a profound morphological modification because of the reduction of sediment flows, and on the other hand, the reduction of freshwater flows into the water table. Actually, it is difficult to associate specific dysfunctions to a single cause. Nevertheless, the following is a summary of those that appear directly or indirectly related to the hydrological disruptions of the Moulouya:

- Decrease of the hydrological function of the Wetland Area:

The Wetland no longer absorbs the floods produced by the river, which formerly ensured the regeneration of the coastal freshwater aquifer used for irrigation. Currently, after the construction of the dams and the drought, this function is only ensured in certain limited areas by some depressions and channels that retain rainwater and drainage water. This situation at first facilitated the conversion of wetland areas for agricultural purposes. But another consequence, namely the increased salinity of

the water and soil, has locally inverted the trend and it seems that agricultural land is being increasingly abandoned.

- Loss of biodiversity

* Among *invertebrates*, the two species, *Venus gallina* and *Cardium edule* have sharply decreased. These species have probably simultaneously suffered elevated pollution levels and changes in habitats (sediments silted up and shallower depths).

* With regard to *fish*, the analysis shows a sharp regression of stocks of migrating and estuary fish and a proliferation of barbels. The Alewife in particular used to be fished in great quantities, but now seems to have disappeared from the area. Its loss is most likely due to the construction of the dams as well as overfishing in the sea during the period when reproductive stock travels upriver, and could also be due to the deterioration of their nurseries from the pollution of the Zaïo sugar refinery wastewater and discharges from the Mechra Homadi Dam.

* The *birds* have probably not suffered excessively serious losses. Nevertheless, salification seems to have affected the high vegetation of the marshes and consequently, its nesting bird species.

* Furthermore, the intensification of agriculture following the construction of the hydraulic facilities has indirectly contributed to the deterioration of the quality of groundwater due to fertilisers and pesticides, which can constitute a serious threat to biodiversity.

Decrease/Loss of economic values (Khattabi, 2002):

The ceasing of activities such as fishing, aquaculture and shellfish gathering in the lower course of the Moulouya has translated into a loss of revenue that has given rise to emigration to foreign countries or to other cities in Morocco, or sometimes to conversion of fishermen into farmers or farm workers. Many farmers, furthermore, have had to change their crops due to the sharp salification of the water.

In contrast, it seems that the *tamarix* genus, which is used for pasturage and gathering of wood, has gained ground in the wadi bed due to the decreased run-off. But these trees are threatened by the operation of sandpits that destroy their habitat.

All of these results could constitute key factors in the global approach to defining the environmental flows of the Moulouya Basin and in deciding whether or not additional allocations via dams are necessary.

IV- GAPS AND ADDITIONAL STUDIES REQUIRED:

Though the results attained to date constitute important base elements for the evaluation of the environmental flows of the lower Moulouya, other studies are necessary for a more global approach integrating all of the components of the system, among which are:

i) On the scientific level:

- More detailed hydrological studies (quantity and quality) based on continuous and precise flow data taken over long periods, especially downriver of the dams;
- Proposal of a joint management approach for surface water and groundwater; the latter require an updated modelling of the transient state functioning of the Triffa water table;
- Updating and conception of new hydrological models;
- Study of tolerance levels of the fauna and flora to hydro-sedimentary disruptions and to the degradation of water quality;
- Improved knowledge on the hydrodynamic functioning of the freshwater-saltwater transition zone;
- Phenological monitoring of habitats, with a study of the spatial-temporal micro-distribution of the vegetation, aquatic fauna and birds (recommended by the MedWetCoast-Moulouya Project Team).

ii) On the institutional and legislative levels:

- Need for good functioning of the mechanisms of dialogue among all users, especially during periods of climatic extremes;
- Need for improved coordination of the different administrations managing the water resources of

the Moulouya Basin. Hopefully the Moulouya Water Basin Agency, instituted in 2000, will play this role;

- Need for improved sensitisation of the decision-makers for a clearer view of the environmental flow concept;
- Need to institute legislative texts and mechanisms that would allow the development, on the basis of the completed studies, of an integrated approach to environmental flows and the evaluation of measures for their allocation.

- Propositions:

To improve the function of Moulouya flows on the environmental level downriver of the dams, we propose the following measures:

On the short term:

- Limiting the amount of water pumped from the Moulay Ali Station, which, in addition, is expensive, in order to allow resurgences downriver of the dams to play their ecological role;
- Controlling and improving the quality of irrigation wastewater by rationalising the pumping of groundwater for irrigation;
- Restoring the quality of the tributaries entering downriver of the dams (Charraa and Zegzel) by installing a sewage treatment plant for the domestic wastewater from the city of Berkane, and by limiting private pumping.

On the longer term:

- Fighting against the silting up of dams, which continues to diminish their useful capacity, by simultaneously carrying out measures of reforestation of the land most exposed to erosion, and mechanical correction of mountain torrent beds. These measures would also diminish the silting up of irrigation channels and thus improve their flow. The construction the dams projected upriver would likewise contribute to diminishing the accretion of sediments in the Mohamed V reservoir.
- Repairing the different facilities damaged after every flood by the inflow of large quantities of sediments. The Regional Office of Agricultural Development of the Moulouya (ORMVAM) is already carrying out an extensive campaign of rehabilitation of irrigation hydrants.
- Promoting water conservation by rationalising its distribution and improving irrigation efficiency. The ORMVAM is attempting to introduce more modern irrigation techniques that consume less water, and is encouraging farmers to adopt them through subsidy incentives.
- Reinforcing the body of laws and regulations that ensue from modern scientific and technological innovations and enforce legislative stipulations through encouragement-dissuasion measures.
- Mobilising additional resources by recycling wastewater of urban areas downriver of the dams, specifically Oujda, Nador and Berkane, which represents a potential of some 40 Mm³/year by 2020.
- In case of extreme need, transferring water from the Sebou Basin or coastal Mediterranean basins, while ensuring that these highly expensive operations do not introduce significant modifications in the ecology of the area.

V- LESSONS TO BE LEARNED:

The principal lessons to be learned from this study can be summed up as follows:

- Modern scientific and technological innovations constitute strong points that, when integrated into a more global approach, are priceless in defining an environmental flow for the lower Moulouya and the conditions necessary for its allocation.

- Despite the critical state of water shortage in the basin and the future pressure foreseen, the major challenge is to find a balance between the water needs of the population and the maintenance of the principal function of the wetlands downriver, which in return benefits the riverside populations. It is thus indispensable to involve this population, especially farmers, in all the stages of management strategy.
- A cost / benefits analysis of all impacts that affect the lives of riverside populations and are at times responsible for their exodus could shift decisions towards the allocation of an environmental flow in the lower course of the Moulouya.
- It is imperative to include the notion of environmental flows in all impact studies before building the dams projected for 2020. This calls for improved scientific and technical knowledge.
- In order to improve the hydrological and environmental functions of the Moulouya, there is definitely an evident need to develop the joint management of water and sediments while integrating the management of drought, which has become a structural phenomenon in the region.

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