Development of a model of economic management of water at the level of watershed in morocco

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Abstract

This work is designed to build a tool for analysis and decision support regarding policy on the allocation of the water resource, allowing a better reflection on the issue of water valorization by the agricultural sector. Thus, an integrated model disaggregated by type of farms was developed for Loukkos basin. This model integrates economic, agronomic and hydraulic data. It can simulate the behavior of farmers faced with changes in public policy and climatic conditions taking into account competition for resources. The effects of two exogenous shocks were simulated by this model: depletion in water resource and change water pricing policy. The main results of these simulations show deviations of economic price of water between agricultural areas and types of farms. The most vulnerable farms are the small ones located in the area of Rmel. In addition to the risk of making some categories of farms in difficulty, a policy designed to increase the rate of water can lead to a shortfall in terms of recipe for the management of the water body. This can arrive if the elasticity of the response of farmers is high, as is the current situation of the ORMVAL. In a drought situation the economic price is four times higher than the rate charged by the ORMVAL. This increase in the water cost mask the effect of an increase water price, indicating that an evaluation of the water pricing policy must take into account inter-annual variability of water cost.

Keywords: water, agriculture, integrated model, drought, water pricing, watershed.

1. Introduction and problematic

The situation in Morocco in the recent years is characterized by a context of water resources scarcity, where drought takes a structural character and pressure of a growing demand of various sectors on water and its allocation. In fact, the country is under pressure and should to be engaged in more rationalization of the use of its water resources to ensure sustainability in term of quantity and quality.

Moroccan agriculture is the most concerned sector by water problem. If irrigated crops contribute by 45% of the added value in agriculture, 33 % of employment in rural areas and 75% of the exports of agricultural products. However, consumed volume is 85% of the mobilized water resources and it leads to negative impact on quality of water resources through the leaching of nitrates and pesticides to groundwater (FAO, 2006).

Considerable efforts in scientific research must be undertaken for a more rational and optimal water resources management. In this alarming context, modelling of basin-level water resources is crucial and will be a tool for analysis and valuable decision support to better manage the allocation of these resources.

The evaluation of the agricultural development policies was strongly present in research which has developed basin models (X. Cai, McKinney, & Lasdon, 2003; X. Cai & Wang, 2006; Pulido Velázquez, Andreu, & Sahuquillo, 2006; Ward, Hurd, Rahmani, & Gollehon, 2006). The sensitivity of water allocation strategies was also present in other research like: (Draper, Jenkins, Kirby, Lund, & Howitt, 2003; Heidecke & Heckelei, 2010; Jakeman & Letcher, 2003; Jenkins et al., 2004; Letcher, Jakeman, & Croke, 2004).

The current study is a contribution to the illumination of this type of issues and for finding tools for best management of water resources at the level of the Loukkos basin, using an integrated model for this basin resolved with the GAMS (General Algebraic Modelling System) software. This model could be a tool of decision-making in policy choices concerning the allocation of water resource. It will allow a better reflection on the issue of to make more added values and to improve water use efficiency (WUE) in the agricultural sector, as well as the study of the problems of water management at the basin and watershed level.

2. Methodology

2.1 Characteristics and interest of an integrated model disaggregated by type of farms for a basin.

The current work concerns the following main axis and objectives:

- Breakdown of production systems by sizes of farms in order to evaluate diversity of situations and to better reflect the constraints imposed by the sizes of the farms on the allocation of resources within the basin.
- Specification of labour factor in the model, and especially family work to better reflect its role in the production systems and the constraints it imposes on achieving the overall product or output at the basin level.
- Introduction of interaction rainfed - irrigated crops in the production systems in the irrigated perimeters to better specify the decision variables and better reflect the mobility of resources within the production systems.
- Taking into account the contribution of secondary-products and fallow land in the income, and the role of these factors on decision-making at farm level.
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2.2 Description of the study area

The Loukkos basin is located in a rainy region where water is not a limiting factor and where it constitutes a positive factor for productive and competitive agriculture.

Figure 1: The watershed of loukkos in Morocco **(ORMVAL, 2005)**

The main problem blocking the modernization and the development of this area is the gap between abundant water resources and low land resources. This situation increases the cost of irrigation water in the basin. Figure 1 shows a simplified diagram of the agro-hydraulic system of the Loukkos basin. It reflects the dynamics of interactions between hydrological and agronomic components and highlights conflicts of use around the allocation of water by different users.

This figure serves as a basic mathematical model adopted in this study and described algebraically in the following chapter.

Figure 2 : hydraulic network components of Loukkos basin.

2.3 Typology of farms

This typology aims to provide a simplified representation of the studied system composed of farms and permits to describe the diversity observed in behaviors, especially for water management. Representative farms in each agricultural area, commonly called "model farms" have been defined after a deep analyze the database of farms in Loukkos perimeter and also with the collaboration of the department of agricultural productions at the ORMVAL. Thus, four groups of farms that are statistically representative of the region in terms of area and number of farms were selected.

The table below shows the structure of each type of farms for each agricultural zone obtained from the database available for 2005-2006 season.

Table 1: Structures of typical farms in each agricultural area of Loukkos basin .

2.4 Structure of the model

The developed model for this study is basically a nonlinear optimization model, where, given a number of constraints, the aim is to seek to maximize an objective function reflecting a social utility function. After the specification of the objective function, in this case: the overall value generated at the sub-basin, and constraint functions, the model is calibrated based on the positive mathematical programming approach (Howitt, 1995).

The proposed model is sufficiently disaggregated in physical and functional units: agricultural demand sites, commune, speculation and source of irrigation water, in order to better reflect the complexity of the exploitation and valuation of irrigation water requirements. Thematically, the structure of the model considers three components: hydrological, economic and agronomic components. Each component is presented with a block of equations (Fig 2).

GAMS CONOPT solver was used for solving the model. It is a nonlinear programming solver which performs an optimization under constraint for reservoircontents, pumping, water use patterns, crop mix, irrigation technologies and mode of access to irrigation water for all basin nodes. TadMod model is based on the actual relationship between the different nodes of the hydrological network. These nodes represent physical entities which can be points of water delivery, reservoirs, groundwater, or agricultural sites. The codification of this model is written in GAMS (The General Algebraic Modelling System), where data, assumptions, constraints, and results are available from the authors upon request.

The model includes:

- Twenty-four agricultural products, including fallow. These products are the most practiced in the basin Loukkos cropping system.
- Five agricultural areas: Rmel, Ksar and Lower Hill, Right Bank, Bour and private irrigation area. In each area, four types of previously defined operations were distinguished.
- 12 periods (12 months, from September to August), allowing a monthly calculation of model variables such as crop water requirements, the releases from the dam for irrigation, stored volume of water in the dam. ...
- Three municipal demand (sites): the city of Larache, Ksar and rural environment.
- Three aquifers that supply one or more agricultural and municipal site as shown in Figure 1.
- One dam: dam Oued el Makhazine.
- Four nodes, each one corresponds to a pumping station that supplies one or more agricultural and municipal areas.
- The model distinguishes within each farm type between rainfed agriculture and irrigated agriculture.
- The demand for municipal and industrial water is set as a parameter.
- The output price is fixed for each crop.
- The requirement of the crop inputs is specific for each agricultural area and type of operation.

- Variable costs par crop were calculated as unit costs per hectare per crop: mechanization costs include the costs of inputs (seeds, plant perennials, fertilizers ...) and the labor costs. The rental prices of land and capital are not included in the costs.
- With regard to the wages of family labor, it has been likened to that of the salary of the hired labor.
- The price of irrigation water is specific for each agricultural area.
- For fallow, forage crops and by-products of crops, yield is expressed in feed units (FU), the unit price has been estimated and fixed at 2 MAD.

Figure 3: structure of the integrated model of the basin.

2.4 Scenarios

2.4.1 Reference Scenario

The reference year chosen for this study corresponds to the 2005-2006 season. This scenario will reflect the use conflicts around the allocation of water in the basin of Loukkos and subsequently used as a reference for the comparison of results from different simulated scenarios.

2.4.2 Simulation 1: drought

This scenario provides insight into the behavior of farmers in conditions of water scarcity. Simulate the impact of a reduction of 70% of water allocation, groundwater recharge and rainfall at the basin level.

2.4.3 Simulation 2: increasing irrigation water prices

This scenario simulates the impact of an increase of irrigation water price applied to surface water in the basin, combined with a 25% tax imposed on groundwater pumping in the case a normal year where there is no shortage of irrigation water. This coupling between increasing price of surface water and groundwater is done in order to avoid over-exploitation of groundwater too. The purpose of this simulation is to determine the behavior of farmers with the variation of water prices, to evaluate their ability to pay current and future royalties and thus to what extent the objectives of the new pricing system can be achieved.

The chosen increasing levels of water for this simulation, estimated on the base of adjustment plan of surface water price across the perimeter Loukkos are:

- Rmel sector: 0.86 MAD/ m^3;
- Low Plains and Hills Area: 0.61 MAD / m^3;
- Plain sector-Right Bank: 0.48 MAD / m^3;
- Private sector: 0.5 MAD / m^3.
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3. Results and Discussion

3.1 Analysis of the reference situation (2005-2006)

3.1.1 Economic Water Prize "Shadow price"

This is the largest and most significant result of the model; it helps to assess the economic value of water in evey agricultural area and for each type of farm. It is defined as the extra added value per

m^3 attributed to irrigation water whereas the contribution of other inputs (fertilizers, seeds ...) is equivalent to the cost of these inputs at market prices.

The comparison between the economic price of water and the cost of water is used to assess the level of water prices that allows sufficient margin to the farmer. In the current state, the agricultural production systems allow to release, across the entire scope of Loukkos basin an average valuation of irrigation of about 0.93 MAD/m^3 of water. This valuation level is relatively low compared to the other irrigated perimeters of the country, because this basin don't suffer from restriction of water supply, but overall it remains above the sustainable cost of water, which guarantees the farmer a positive margin benefit. However, the economic price of water in agricultural areas varies in the range of 0.75 MAD/m^3 for the Right Bank agricultural area MAD and 1.75 MAD/m^3 for Rmel area as shown by the model results summarized in the table below.

Table 2: Value of the opportunity cost of water in Loukkos perimeter by area and type of farms (MAD/ m^3)

Analysis of the results reveals deviation magnitudes of economic price of water by agricultural areas and types of farms.

Intra-regional difference in sensitivity to economic price of irrigation water changes for the level of supply of irrigation water is more remarkable in the agricultural area of Rmel, including the farms which has an area greater than 10 hectares registered a marginal value of irrigation water use two times larger than that of farms smaller than 10 ha. This can be explained by the fact that large farms reserve more land to crops of high value (strawberry, melon, watermelon and tomato) in comparison with sugar cane that has a low water use productivity and the use on the other hand of more economical irrigation techniques including drip irrigation. Thus, the small and medium-sized farms in the agricultural zone of Rmel are more sensitive to the increased prices of surface water.

The private pumping sector (using groundwater for irrigation) has an opportunity of water cost that is equal to the financial cost and is low compared to other agricultural areas. This can be explained by the abundance of this resource and the low cost of pumping water equivalent to 0.4 MAD/m^3.

3.1.2 Agricultural Production

Agricultural area in the basin Loukkos is equal to 83,899 ha including 24,425 ha of irrigated area and 59,474 ha of rainfed area.

Loukkos Basin is located in an area of heavy rainfall which means no restriction on irrigation water and that provides to the farmer a large and open for cultural practices and cropping system.

Cereals are still the base of the crop rotation with an occupied area equal to 9% of the total agricultural area of the irrigated farms against 26% in average for rainfed farms. It includes durum wheat and barley. Among the motivations encouraging farmers to grow cereals there is the low production cost, the duration of their sale allows entering to the market many times throughout the year; in addition to the market conditions, despite fluctuations, are still profitable.

Vegetable crops occupy 34% of the total cultivated area in the scope of which 27% is grown in the area of Rmel and private pumping sector.

The obtained yields trough the model are very close or either equal to real yields in the field (official data) which reflects the reliability of the model results.

Table 3: Comparison of yields obtained from the model to the real ones in the field (Qx/ha).

3.1.3 Gross margin

The total gross margin level in Loukkos basin for the reference years is estimated at 750.52 million dirhams including the one for Rmel sector that attained 30%, equivalent to 225.46 million dirhams. The gross margin of each agricultural area and type of operation is described in the following table:

Table 4: Gross margin per agricultural area and type of farms in Millions of MAD (reference year)

Table 5: Gross margin per hectare in MAD (reference year)

Tables above show that within the same agricultural area each type of farm has a gross margin per hectare different given its agricultural potential, its cropping system, its technical level and its financial resources. This permits to predict a specific behavior to each farm type in front of an external shock. The private pumping sector registered a higher gross margin per hectare .

3.1.4 Irrigation water consumption

The total water demand for irrigation in Loukkos is equal to 189.52 million m^3, of which 17% is supplied mainly by the groundwater of Rmel (31.96 million m^3) and 83% is provided by the El Oued Makhazine dam (157 56 million m^3). Farms area between 5 and 10 ha located in the agricultural area of Rmel consume alone 44% of the allocations of surface water for irrigation. This demand for irrigation water by month is shown the following figure.

Figure 4: Evolution of irrigation water demand for the basin of Loukkos (million m^3)

It is clear from the above figure that: Demand for irrigation water is low at the beginning of the cropping sear. Starting from March when the rains start to become less abundant and the water requirements of crops s 'accentuate the demand for irrigation water becomes more important, and it reached a maximum of 38.5 million m^3 in June.

The volume of groundwater and surface water used for irrigation by the four farm types and in different agricultural areas is presented in the following table.

Table 6: Consumption of agricultural irrigation water by area and type of farms million m3 (base year)

3.1.5 Water resources:

- Surface water: dam Oued El Makhazine :

From November charging the dam rainwater is increasing to a peak in January and remains in the relatively stable thereafter. Then, there is a lowering of the volume of water stored in the dam, this is the one hand, reduction of rainwater as well as the phenomenon of evaporation, which peaked in July and August (these two months alone account for 30% of total annual evaporation), and, secondly, the increase in crop needs irrigation water.

Figure 5: Evolution of the volume of water stored in the dam of El Oued Makhazine million m^3 (referenceYear)

- Groundwater:

Figure 6: Evolution of the volume of water stored in aquifers in million m3 (reference Year)

3.2 Results of the simulation (1): Year of Drought

The effects of drought are much more expressed in the case of rainfed crops, the gross margin per hectare and the area under cultivation in this segment decreased significantly (respectively 93% and 87% on average). In fact, the reaction of the farmer would result in this case by the land abondon land to be left as fallow.

However, irrigated agriculture is relatively less affected by this phenomenon. This constitutes a control device to compensate and alleviate the negative effects of drought.

Indeed, private pumping sector is less vulnerable to drought impacts that are minor because the groundwater remains sufficient to irrigate all the agricultural area in this sector in a dry year. The gross margin per hectare, the used amount of water and the cultivated area has not substantially changed for the reference year.

Furthermore, in situations of drought, released volumes of water from the dam has a substantial reduction, which could induce adverse effects as a significant reduction in the quantities of surface water used for irrigation estimated to 37% and loss of production. This would result in a reduction of gross margin per hectare estimated to 32% on average for the areas using surface water for irrigation. In fact, farmers are moving to abandon a part of land or decreasing the area allocated to irrigated crops.

In terms of economic price, there is a significant increase in the marginal value of water relative to the reference situation. This value increased from 0.93 MAD / m^3 observed in the reference year to 2.74 MAD/ m^3. In fact, water resource is becoming a constraint for production in the basin Loukkos during a dry year.

Table 7: Effect of drought on the economic price of water in MAD / m^3

Farms larger than 10 ha of Rmel sector showed the highest valuation level of water in all Loukoos area. This is explained by the fact that this category of farm devoted more to the cultivation of crops with high water productivity and implemented water-saving measures such as drip irrigation.

Moreover, the fact that the economic price of water varies greatly from an agricultural area to another, the average opportunity cost of water from the higher surface is found in the area Rmel (average 5.75 MAD/ m³).The area of Ksar and low collins has the lowest valuation level (2.24 MAD / m³). Regarding the private pumping sector that uses groundwater for irrigation, no change was found in the economic price. This can be explained by the fact that the private sector is in a region where water is relatively available in the aquifer supplying this sector and the volume of water in aquifers support the needs of water form for the dry year.

Table 8: Simulation Results "drought"

3.3 Results of the simulation (2): Increase in the price of irrigation water

3.3.1 Normal year : Sim 2/A

The marginal value of water has increased compared to the reference year following the Increase in water price to reach MAD 1.16 / m³ on average. This valuation level is generally higher than the sustainable cost.

In order to assess the level of water prices that allows sufficient margin to the farmer, comparison of the valuation of m3 of water in the different agricultural regions of the perimeter with the new specific financial price for each agricultural area (sustainable cost) was done.

Table 9: Calculation of the ratio between sustainable cost and economic cost if the SIM APE1 (shadow price / sustainable cost).

The data from the table shows that farms with an area lower than 10 ha located in the area Rmel have the lowest cost. However, the average level of valuation remains well above the sustainable cost.

Nevertheless, in the other agricultural areas (Ksar and Low collins, right bank and large farms in Rmel), recovery of water is at least 2 times the sustainable cost and therefore not a limiting factor to the complete coverage of sustainable cost of water service.

The coverage of sustainable cost may weaken certain categories of farms, particularly farms smaller than 10 ha located in Rmel sector.

The increase in price is also reflected in a reduction of 11% in surface water. Since the price per m^3 of water becomes more expensive and farmers will tend to reduce and rationalize the use of water, while choosing the crops that permits less water consumption and that are valuating more this resource . However, the use of groundwater for irrigation is insensitive to taxation pumping (reduction of 1%). This is justified by the abundance of groundwater resources in the watershed Loukkos.

Therefore, increasing the tariffs generates a rational use of water and in fact water saving. However, this decrease in water consumption results in reduced volumes of water paid by farmers and therefore an increase in the cost of water per m^3 since much of this cost consists of fixed operation and equipment maintenance costs. This situation should lead to good reasoning passage of current tariff to sustainable cost in order to avoid the adverse effects of increased water tariffs in terms of revenue of the water not "sold" by the ORMVA of Loukkos.

Increasing tariffs resulted in an increase of approximately 5.18% of the area for rainfed crops replacing the area allocated to irrigated crops. Indeed, when the price of water becomes greater than the additional profit generated by irrigation for agriculture, the farmer will have to phase out the benefits from irrigated crops and adopt rainfed crops. This situation reflects the interchangeability of of cultivated area between irrigated rainfed areas (substitution effect).
The main results obtained from increasing tariff of water irrigation at the end of the rotation are:

- Substitution effect of irrigated land by rainfed ones increased in the area of the right bank and Ksar and low Collins with the registration of a decrease of 7% of the irrigated area.
- Sugar cane crop has registred the most significant decline in terms of allocated area, so it is considered the most sensitive crop to a water tariff increase among all irrigated crops.
- Rising cost of groundwater has not had a great impact on land occupation in the private pumping sector.
- The following table illustrates the change in the gross margin per hectare following the rise in water price.
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Table 10: Reduction rate in gross margin per hectare in each area and type of farms holdings after an increase in water price.

The table shows that: The increase in the price of water results in a significant decrease in gross margin per hectare in all agricultural areas and for all types of farms.
Farms smaller than 10 ha located in the area of Rmel reveal the the most important decrease in gross margin per hectare. Those farms are characterized by a high sensitivity to the increase in water price. Given the ownership structure in this Rmel sector wich has the majority of land as a part cooperatives of agrarian reform with a size of about 5 ha, this sector is the most vulnerable to surface water price increases.

Table 11: Results of the increase in the price of irrigation water in Loukkos basin.

3.3.2 Dry Year : SIM 2/B

The simulation reproduces almost the same results as the simulation of the dry year. Thus, the effect of drought is far more important than the redefinition of surface water tariff and groundwater taxation and the decision of farmers in a dry year is not too influenced by an increase in water tariffs.

Table 12: Results of the simulation tariff under drought aggregated at Loukkos basin

Conclusion

Analysis of the results reveals important differences between the economic price of water in agricultural areas and types of farms. The most vulnerable farms are the small ones and particularly those in the area of Rmel. For those farms, the economic price approximates the financial price which makes them very sensitive to any increase in water tariff. Increasing water tariff in normal years necessarily leads to a decrease in demand for irrigation water in addition to the risk to make certain categories of farms in difficulty. This reduction would be around 11% when

tariff adjustment plan is adopted, which indicates that a policy to improve the revenue of the management body of water can lead to a reduction in terms of commercialized volumes of water if the elasticity of the response of farmers is high, as is the current situation of ORMVAL.
The model results show for drought situation that in addition to a substantial reduction of rainfed area, irrigated areas are also characterized by a decrease up to 38% in the case of severe drought (case of Ksar area and low collins). The economic price in drought is four times higher than the rtariff charged by the ORMVAL. This substantial increase in the economic cost of water even mask the effect of increasing the water price in drought, it shall indicate that an evaluation of the policy of water tariff must consider the inter-annual variability of the economic price of water.

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Tables and figures

Table 1: Structures of typical farms in each agricultural area of the basin Loukkos (ORMVAL)

Nomination	Type 1		Type 2		Type 3		Type 4	
Area per ha	Less than 5 ha		Between 5 and 10 ha		Between 10 and 20 ha		More than 20 ha	
Sector	Number	Average area	number	Average area	Number	Average area	Number	Average area
Rmel	460	3.84	1650	6	81	13.61	51	23.4
Private puming area	60	2.82	37	8.1	75	14.33	51	29.5
Ksar and low Collins	1201	1	142	6	68	12	46	26,5
Right bank	2251	1	223	6	135	13	31	46,4
Bour	4902	4	1464	7.8	705	16.3	203	67,7

Table 2: Value of the opportunity cost of water in Loukkos perimeter by area and type of farms (MAD/ m^3)

Area/Farm type	*Type 1*	*Type 2*	*Type 3*	*Type 4*	Main value /area
Rmel	0,70	0,71	2,06	2,01	1,75
Private puming area	0,4	0,4	0,4	0,4	0,4
Right bank	0,77	1,02	0,78	0,69	0,75
Ksar and low Collins	1	1,51	0,96	0,69	0,82

Table 3: Comparison of yields obtained from the model to the real ones in the field (Qx/ha)

Area	Rmel		Private pumping sector		Right bank		Ksar low Collins		Rainfed area	
Crop	Field	model	Field	model	Field	model	Field	model	Field	model
wheat	39	41,38	30	41,58		41,58		41,39		
wheat rainfed			27	31,25	38	36,33	35	32,21	33	32,21
durumrainfed					36	34,6	34	30,67	31	30,67
barley rainfed					22	25,97	22,5	23,01	20	23,01
Sugar can	850	939,8			925	923,4	924	921,9		
sugar beets					560	594	565	591,1		
potato	786	809,3	820	811,6					400	322,8
strawberry	513	548,3	550	554,4						
tomato	508	589,1	590	589,1	590	587,9	592	587		
melon	456	435,6	430	435,6	400	434,6	370	435,1		
watermelon	450	447,5	450	447,5						

Table 4: Gross margin per agricultural area and type of farms in Millions of MAD (reference year)

Farm size/type	Type1	Type2	Type3	Type4	Gross Margin /area
Rmel	27,08	132,21	42,66	23,50	225,46
Puming private sector	6,33	9,27	53,53	41,80	110,95
Right bank	56,89	31,07	38,28	27,14	153,38
Ksar and low Collins	18,15	13,94	10,73	12,04	54,88
Rainfed area	70,04	38,84	43,66	53,26	205,82
Gross margin / farm type	178,51	225,35	188,89	157,76	750,52

Table 5: Gross margin per hectare in MAD (reference year)

Farm size/type	Type1	Type2	Type3	Type4
Rmel	15333,84	13354,67	38705,82	19694,20
Puming private sector	37444,92	30957,41	49816,16	27785,27
Right bank	25274,91	23222,70	21813,23	18868,34
Ksar and low Collins	15116,95	16370,54	13155,63	9884,77

Table 6: Consumption of agricultural irrigation water by area and type of farms million m3 (base year)

Farm size/type	Type 1	Type 2	Type 3	Type 4	total per sector
Rmel	10,88	70,52	10,36	9,79	101,56
Right bank	14,15	5,65	9,66	6,05	35,53
Ksar and low Collins	7,614	3,461	4,40	4,97	20,46
Total consumed urface water volume per farm type	32,64	79,64	24,43	20,83	157,56
Private pumping sector	1,50	2,57	14,00	13,87	31,96
Total consumed water volume per farm type	34,15	82,22	38,44	34,70	189,52

Table 7: Effect of drought on the economic price of water in MAD / m³

Farm size/type	type 1	Type 2	Type 3	Type 4	Average/area
Rmel	3,75	4,31	5,7	6,48	5,75
Private pumping secotr	0,4	0,4	0,4	0,4	0,4
Right bank	2,8	3,45	2,52	2,39	2,57
Ksar and loww Collin	2,98	3,91	2,71	1,88	2,24
Average/farm type	2,46	2,80	2,81	2,49	2,74

Table 8: Simulation Results "drought"

	reference year	drought	Variation /reference year
Surface water use in Mm^3	157,56	88,65	- 44 %
Groundwater use in Mm^3	31,96	34,65	+ 8,4%
Totale water use in Mm^3	189,52	132,44	-30,1 %
Value of water (MAD/m^3)	0,93	2,74	194,6 %
Agriculture net margine en Million MAD	750,52	421,76	- 43,8
Irrigated area (ha)	24425	18346	- 24,88
Rainfed area (ha)	48278	7710	-84,03
Fallow area	11195	57845	416,66

Table 9: Calculation of the ratio between sustainable cost and economic cost if the SIM APE1 (shadow price / sustainable cost)

Farm size/type Area	Type 1	Type 2	Type 3	Type 4	Ratio per agriculture area
Rmel	1,08	1,13	2,8	3,01	2,54
Puming private sector	1	1	1	1	1
Right bank	2,22	3,04	2,125	1,89	2,33
Ksar and low Collins	2,06	2,98	1,95	1,47	2,11

Table 10: Reduction rate in gross margin per hectare in each area and type of farms holdings after an increase in water price.

Farm size/type Area	Type 1	Type 2	Type 3	Type 4	Average per area
Rmel	-24,67	-28,7	-17,63	-19,12	-20,77
Puming private sector	-4,01	-4,03	-4,04	-4,67	-4,15
Right bank	-16,02	-11,48	-14,66	-12,09	-13,64
Ksar and low Collins	-13,52	-9,50	-13,47	-11,99	-12,00

Table 11: Results of the increase in the price of irrigation water in Loukkos basin

	Reference year (1)	Sim 2/A	Variation rate
Use of surface water in Mm^3	157,56	140,04	-11,12
Use of groundwater in Mm^3	31,96	31,4	-1,75
Marginal value of water in (MAD/m^3)	1,05	1,32	+25,71
Total water use en Mm^3	189,52	171,44	-9,54
Gross margin per hectare in MAD	20064,37	18196,34	-9,31
Irrigated area (ha)	24425,19	23159,5	-5,18
Rainfed area (ha)	59474,27	60739,96	+2,13

Table 12: Results of the simulation tariff under drought aggregated at Loukkos basin

	Dry year	Sim 2/B
Use of surface water in Mm^3	2,74	2,79
Use of groundwater in Mm^3	97,79	97,73
Marginal value of water in (MAD/m^3)	34,65	34.04
Total water use en Mm^3	15124,4	14179,3
Gross margin per hectare in MAD	18346,07	18307,45
Irrigated area (ha)	7710	7709,5
Rainfed area (ha)	57845	57882

Figure 1: The watershed of loukkos in Morocco

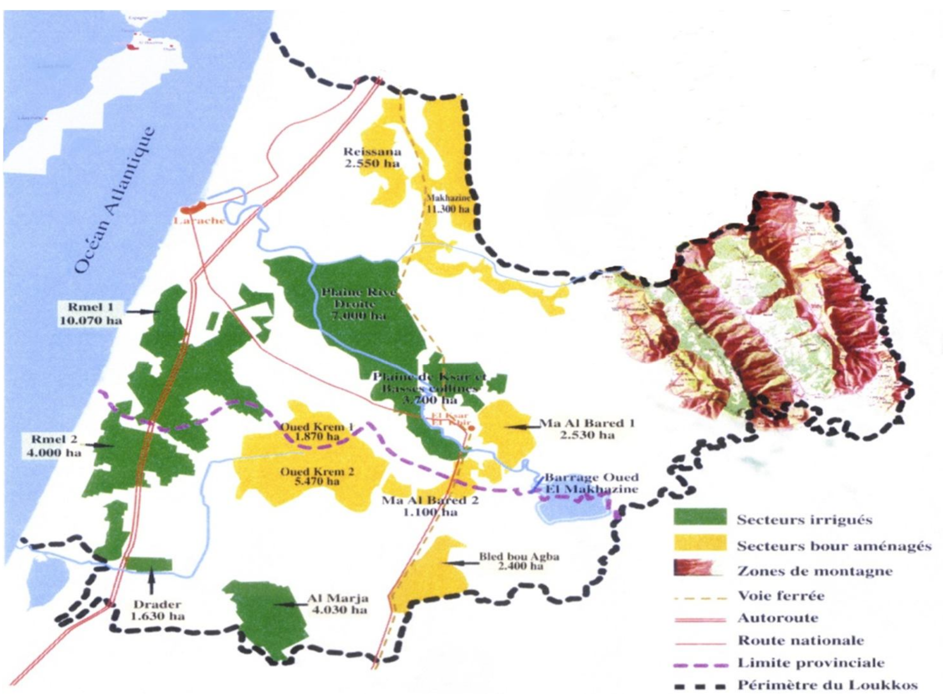
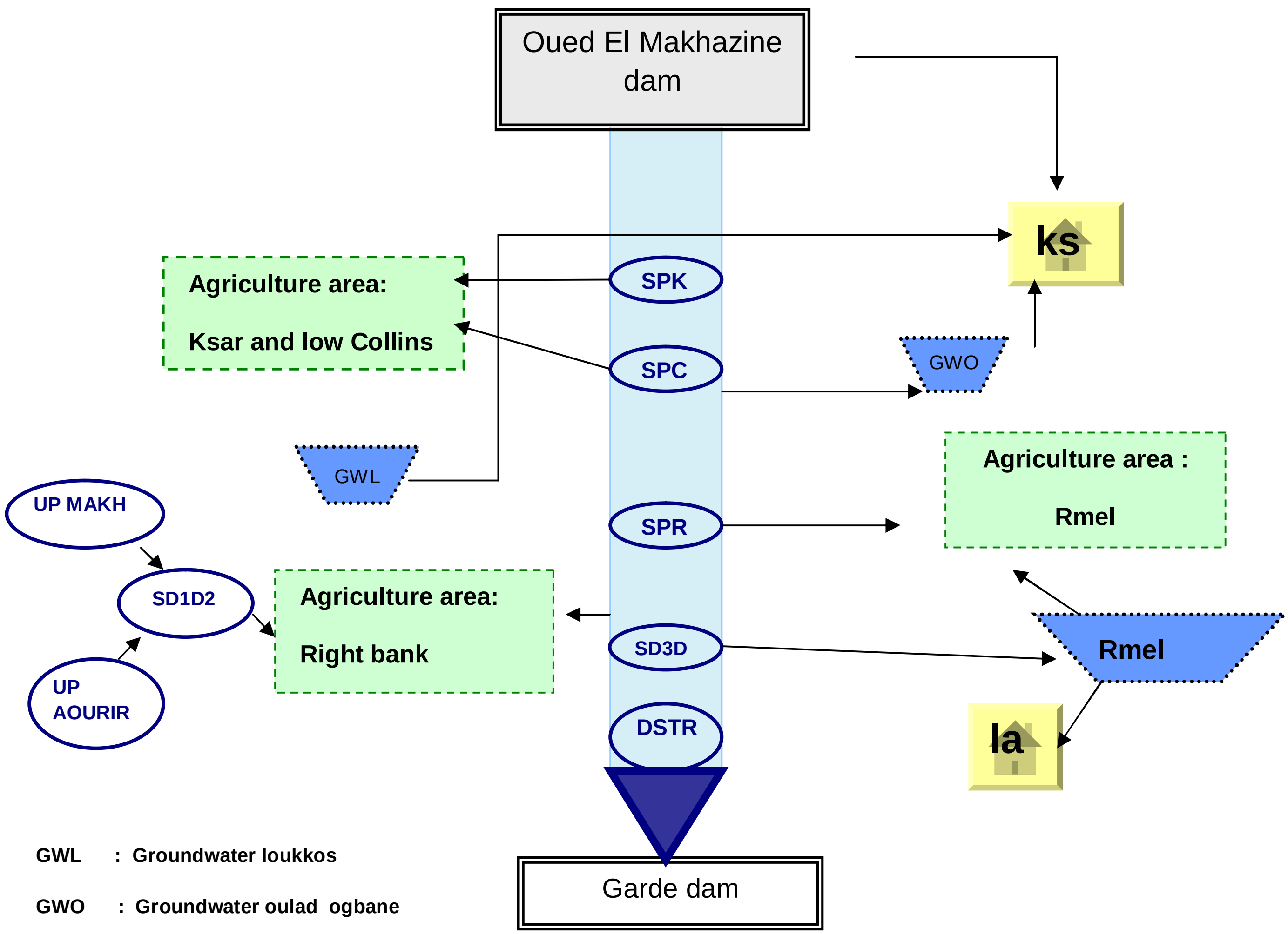


Figure2: hydraulic network components of Loukkos basin



GWL : Groundwater loukkos

GWO : Groundwater oulad ogbane

GWR : Groundwater Rmel

KS : Ksar Kbir CitY

LA : larrache City

: River/distribution node

: Water distribution direction

Figure 3: structure of the integrated model of the basin.

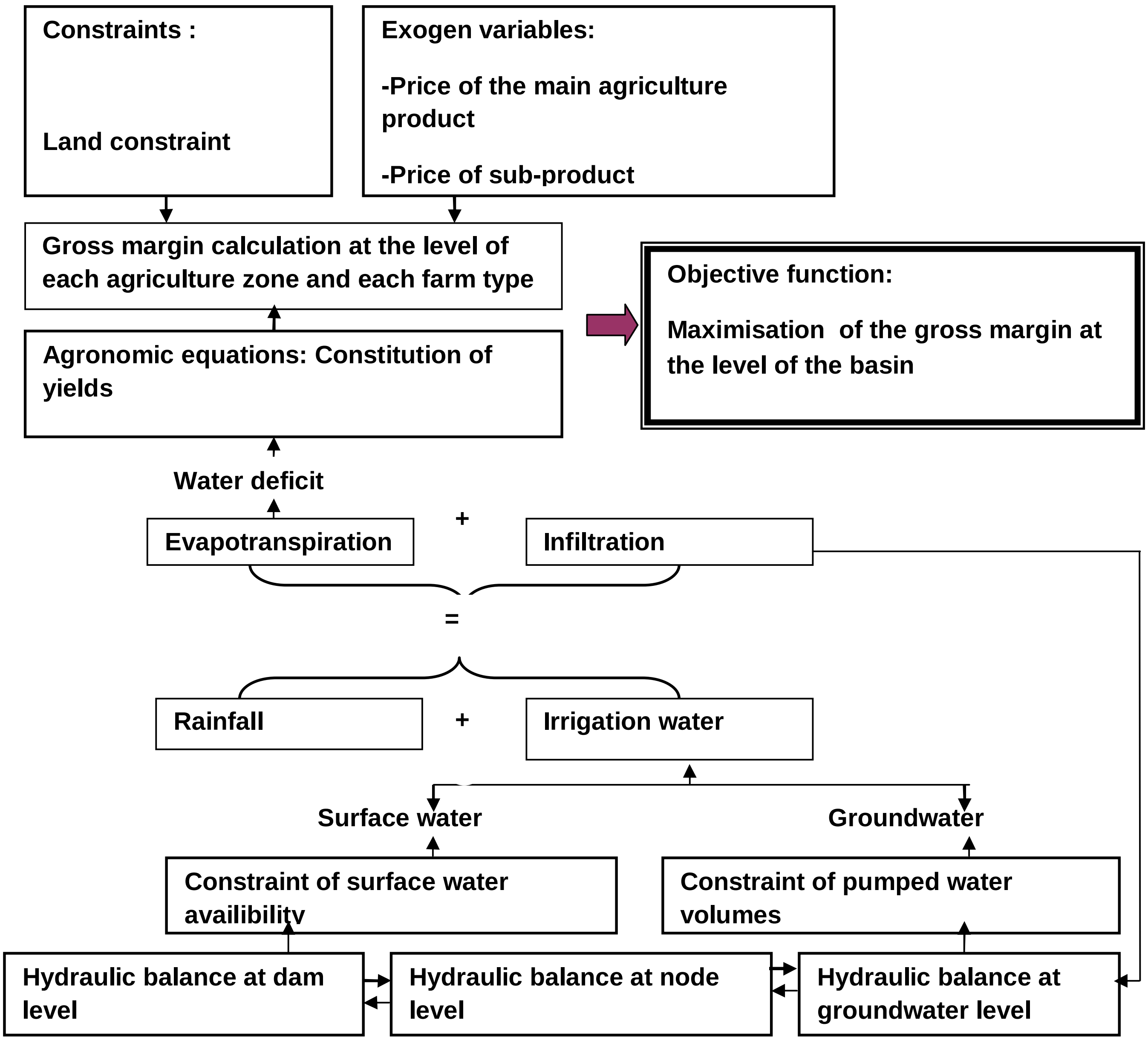


Figure 4: Evolution of irrigation water demand for the basin of Loukkos (million m^3)

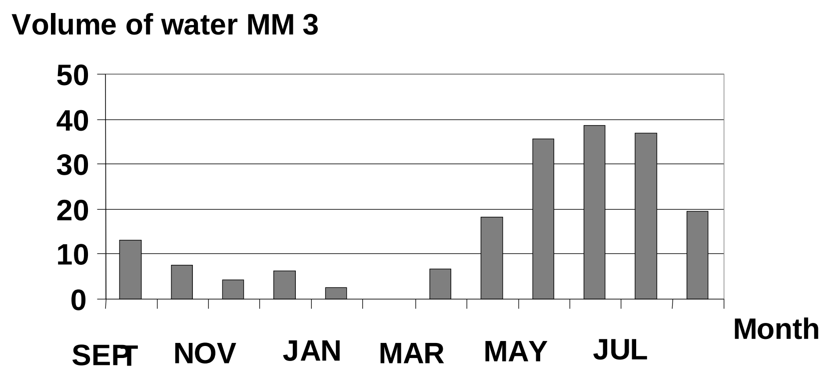


Figure 5: Evolution of the volume of water stored in the dam of El Oued Makhazine million m^3 (referenceYear)

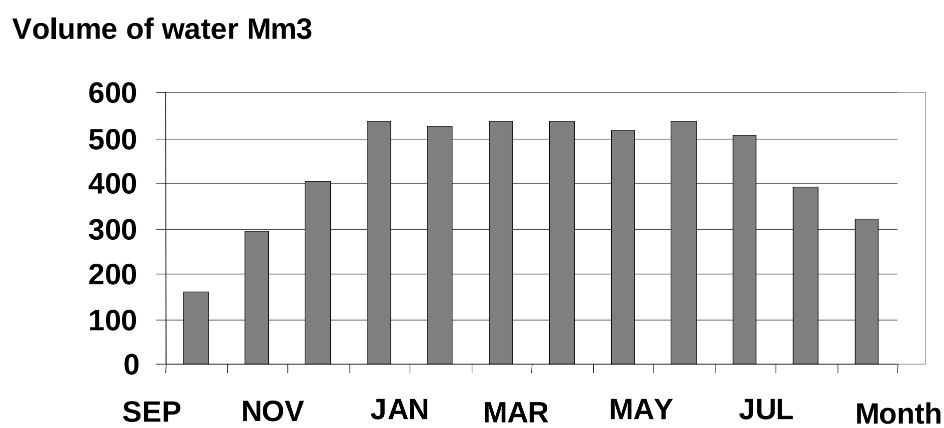


Figure 6: Evolution of the volume of water stored in aquifers in million m3