Construction of a Water Management Support System for the Chekka Bay area (Lebanon)

Sandra Lanini[1], Michel Bakalowicz[2], Ahmad El-Hajj[2], Nathalie Dörfliger[1]

[1] BRGM, Water Division, RMD Unit, 1039 rue de Pinville, F-34000 Montpellier, phone + 33 4 67 15 79 65; fax + 33 4 67 64 58 51; e-mail: s.lanini@brgm.fr

[2] *CREEN-ESIB, Engineering Faculty,* Riad El Solh, BP 11-0514 BEYROUTH 1107 2050 (Lebanon), Michel.Bakalowicz@gmail.com

Abstract

This paper is part of the European MEDITATE project (MEditerranean Development of Innovative Technologies for integrAted water managEment).

Chekka karst submarine springs in Lebanon are considered as the most productive ones in the Mediterranean Sea. This fresh water could represent an interesting water resource in a region that has to face both water scarcity and an increasing demand. But their potential exploitation is only an option among others to fill the current or future gap between water supply and demand. In order to support Lebanese water authorities in their way toward sustainable water management of the Chekka Bay area, tools and guidelines are being elaborated within the MEDITATE European project. The project has adopted an integrated approach relying on a hydrogeological study of the submarine spring catchment, a social and economical survey at a larger scale and the integration of all these information and knowledge in a numerical model.

The study area covers 1200 km^2 of the North Lebanon district. It includes three rivers (Abou Ali, Asfour and Jawz) and their watershed. Jurassic and Cenomanian limestone form the two main aquifers of the area. The most important water consumption is for irrigation then for domestic use with a population of nearly 1 million persons in the study area.

A model has been developed with the WEAP software (SEI, 2005a) to simulate the dynamical links of water resource and water demand in this case study, and to explore the system behaviour according to different management options and evolution scenarios. After calibration, the model was run for a reference year. Effective rainfall is estimated to almost 500 million cubic meters/year on the three watersheds, and 750 million cubic meters/year on the overall study area. It appears that almost 80% of this water are infiltrated. But this amount of water input is clearly underestimated in the Abou Ali watershed as shown by the comparison of simulated and observed river flowrates. The discrepancies can be explained both by the inaccuracy of available time series data (especially an under-evaluation of snowy precipitations) and by the poor knowledge of aquifer recharge areas. Actually, the hydrogeological catchment from which recharge should be calculated is probably much wider than the topographic one used in the model. This water resource has to be compared to the total water demand estimated around 215 million cubic meters in 2005, and which could increase up to 70 % by the year 2030 in a "business as usual" scenario.

The significant contribution of the WEAP model to this study is that it can evaluate at the same time resource and demand at a monthly time step. It will be shortly applied to simulate the different scenarios of water management that were defined after two Water Vision Workshops that have been organised with the local stakeholders. At the same time, a cost-effectiveness analysis (CEA) of different measures that could bring new resources to the area or could allow decreasing or stabilising the water demand has been performed. The combined results of the WEAP model and of the CEA will allow providing informed guidelines to Lebanese water authorities.

***Keywords** : Lebanon, Chekka, WEAP, water demand, water supply*

Introduction

The present work is part of EU project MEDITATE (Mediterranean Development of Innovative Technologies for integrAted waTer management of the 6th Framework program (PL509112)) which aimed at developing a water management support system (WMSS) at the scale of water catchment and integrating alternative water resources such as fresh water from karstic submarine springs or wastewater treatment and reuse. Water scarcity mitigation is an important challenge in many arid and semi-arid regions in Mediterranean and Middle East countries.

Chekka karst submarine springs in Lebanon are considered as the most productive ones in the Mediterranean Sea. This fresh water could represent an interesting water resource in a region that has to face both water scarcity and an increasing demand. But their potential exploitation is only an option among others to fill the current or future gap between water supply and demand. For Lebanon, the population growth is highly increasing and greatly contributes to damage the water balance by increasing of the total water demand. Water resource availability is therefore becoming an increasingly limiting factor for economic development. In order to support Lebanese water authorities in their way toward sustainable water management of the Chekka Bay area, tools and guidelines are being elaborated within the MEDITATE European project. The project has adopted an integrated approach relying on a hydrogeological study of the submarine spring catchment, a social and economical survey at a larger scale and the integration of all these information and knowledge in a numerical model.

The Lebanese case study has been delimitated regarding both the hydrogeological system and the water management organisation around the Chekka Bay and its submarine springs. It corresponds to Koura, Bcharré, Zgharta, Batroun and Tripoli-Minieh-Donnieh cazas. The case study area is about 1200 km^2, and includes three river watersheds: Abou Ali, Asfour and Jawz rivers

Case study – Chekka catchment in Lebanon

The Lebanon case study is the Chekka Bay area and its submarine springs (Bakalowicz et al., 2008, within the proceedings of WWC). The study area can not be restricted to the submarine springs catchment as both the hydrogeological system and the water management organisation has to be considered. The case study has thus been delimitated regarding administrative boundaries. It corresponds to five of the six cazas of the North Lebanon Mohafazat, namely: El Koura, Bcharré, Zgharta, El Batroun and Tripoli-Minieh-Donnieh. The area is about 1200 km^2, 50 km from East to West and 40 km from North to South. It includes three rivers and their watershed: El Abou Ali river, El Asfour river and El Jawz river. The study area typifies the Lebanese coast: it consists of a narrow plain followed inland by a series of foothills, plateau, then rising through steep slopes to the coastal mountain range. Jurassic and Cenomanian-Turonian limestones form the two main aquifers of the Chekka Bay area, separated by a thick impermeable layer. The Jurassic limestone outcrops only in the upper part of the area, and probably exists very deeply and confined in Chekka area. The Cretaceous limestone is covered by the thick impermeable Senonian marls, which locally confine the Cretaceous aquifer.

Conceptual model of water resources

The WEAP tool has been selected to be used within the framework of this project. It is one of the components of Integrated Water management support tool or system that can be implemented relatively easily to assess scenarios on various water allocation strategies for example, in a user-friendly environment. WEAP is the acronym for Water Evaluation and Planning System, originally developed by the Stockholm Environment Institute at Boston in USA (SEI, 2005a). It is distinguished by its integrated approach to simulating water systems and by its policy orientation; it places the demand site of the equation –water use patterns, equipment efficiencies, re-use, prices and allocation – on a equal footing with the supply site – streamflow, groundwater, reservoirs and water transfers.

WEAP allows representing the system to be modelled in terms of water management issues, in terms of its various supply sources, withdrawal, transmission and wastewater treatment facilities, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis and to reflect the limits imposed by restricted data. It integrates a modern Graphic user Interface (GUI), a robust solution algorithm to solve the water allocation problem, and the integration of hydrologic sub-modules that include a conceptual rainfall runoff, an alluvial groundwater model, and a stream water quality model (Yates et al., 2005). WEAP model simulations are constructed as a set of scenarios, where simulation time steps can be as short as one day, to weekly, to monthly, or even seasonally with a time horizon from as short as a single year to more than 100 years (Yates et al., 2005). In our case, a monthly time step has been used.

Different hydrological units were defined to represent the hydrological functioning (both surface and groundwater) of the study area (Figure 1):

- The Abou Ali river basin is divided into two sub catchments to take into account the geology, the hydrography and the climate
- The Chekka submarine karst spring catchment (CSKS) is represented as a single reservoir fed by two river sub-catchments (downstream parts of Asfour and Jawz river watersheds).
- The upper part of the Asfour river catchment is a 26 km^2 reservoir located on cretaceous formations;
- The upper part of the Jawz river catchment is a 98 km^2 reservoir, which comprises the main spring of the river (Dallé Spring).

Real aquifer geometries and properties are relatively unknown, but for the purpose of modelling, they are represented as independent and continuous reservoirs fed by infiltration through the sub-catchment surface. Each aquifer is associated to one sub_catchment which supplies it with water except for the *CSKS* which is fed both by the downstream part of the Asfour watershed (*Chekka Submarine Spring Catchment-Asfour*) and by the downstream part of the Jawz watershed (*Chekka Submarine Spring Catchment-Jawz).* In order to satisfy some components of the water demand for Tripoli and Koura cazas, two groundwater reservoirs were added in the model (*Tripoli GW* and *Koura GW*). As they are located outside of the three river watersheds, their recharge can not be calculated. A rough estimation has given mean effective rainfalls of respectively 135 and 50 MCM/year on the part which is in the Tripoli-Minnieh-Donieh caza and on the one in Koura. In order to allow the model simulations and to satisfy water requirement, a natural recharge of respectively 90 and 40MCM/year (distributed between November and February) is imposed in the corresponding reservoirs (*Tripoli GW* and *Koura GW*).

Each river of the study area was divided into two reaches to fit with the hydrological units.

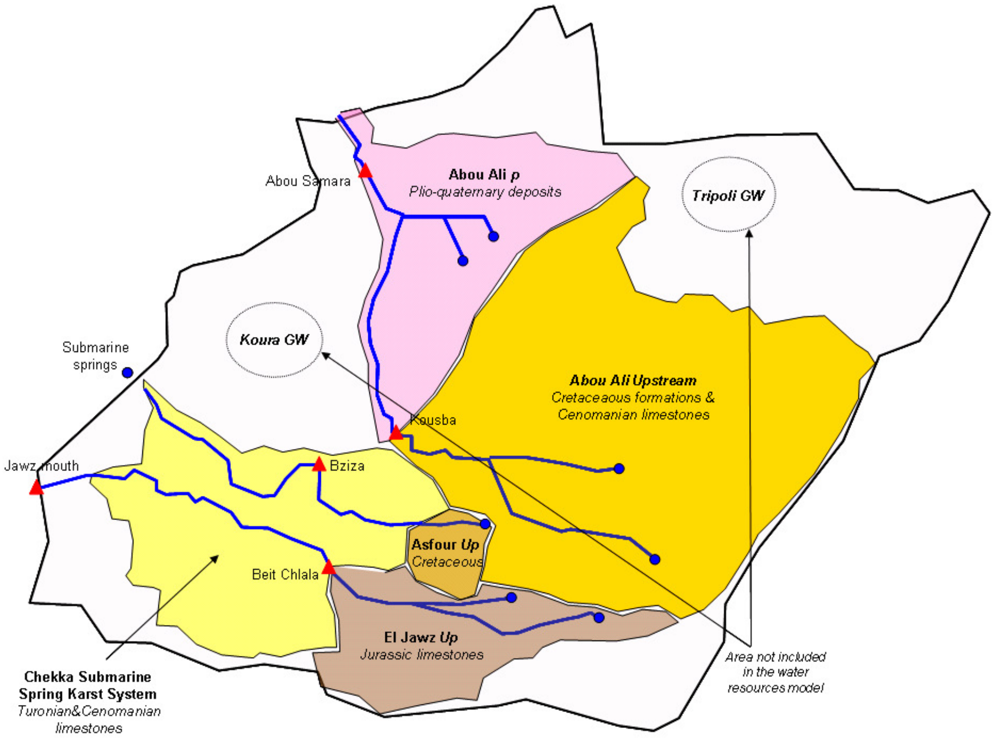

Figure 1 : Definition of five groundwater reservoirs in the Lebanese case study

Description of current water resources of the area

The effective rainfall is calculated by the WEAP model at a monthly time step as the minimum of observed precipitation and potential evapotranspiration. With the same climatic data, a rough estimation of the annual water input on the part of the study area which is out of the river watersheds can be proposed. It leads to an additional amount of 250MCM/year (from which 135 MCM/year for Minieh-Donnieh casa and 50 MCM/year for Koura casa). When going into details for the three watersheds, it appears that 80% of the 496 MCM/year are infiltrated. But this annual amount of effective rainfall is probably underestimated as calculation on flow rate data[1] for the three rivers gives an annual volume of surface water of 545 MCM/year.

Return flows

For each drinking water and tourist demand node, it is assumed that only 20% of water is consumed. It means that 80% of demand water return to the hydrosystem as wastewater. As there is currently no operational wastewater treatment plant in the study area, wastewater goes directly to rivers or to the sea, or is infiltrated. For industrial nodes, the consumption is set to only 10% of the demand, but as industries are located near the sea, wastewater is supposed to flow directly toward the Mediterranean Sea. For agriculture, consumption represents 100% of the demand (thus there is no return flow).

[1] Abou Samara station on Abou Ali (data 1948-1968), Mouth station on Jawz (data 1966-1973) and Bziza station on Asfour (data 1969-1974). Monthly average flow rate given by Office National du Litani or extracted from the PNUD report (1970).

Description of current water demand of the area

Drinking Water

There is one drinking water demand node per casa in the model. The demand is evaluated as the product of the number of inhabitants by the mean annual consumption per capita (between 120 and 200 l/inhab/d in 2005). Monthly variations are not taken into account. The rate of network losses, defined as (Supply-Demand)/Supply is set to 45% in 2005.

Tourism

There is one or two tourist demand node per casa (one on the seafront and possibly one in the mountains). Demand is calculated as the product of the number of beds by the filling rate by the mean consumption by bed (300 l). Moreover, for Tripoli1 (coastal tourism), Batroun1, Bcharré and Zgharta, a constant volume is added to represent swimming-pools in hotels (1200 m^3 filled twice a year). Monthly variations of demand are taken into account as follow:

- for littoral tourism, 90% of the demand is concentrated in summer (from May to October) (Batroun1, Tripoli1, Koura),
- for mountain tourism, 90% of the demand is concentrated in winter (from October to March) (Batroun2, Tripoli2),
- for mountain tourism, 72% of the demand is concentrated in winter (October to March) with a residual tourist activity in other seasons (Bcharré, Zgharta).

Industry

Two industrial sites are defined: the first one near Tripoli city and the second around Chekka (in Batroun casa). For both of them, the water demand is assumed to be proportional to the Drinking Water Demand of the casa. The coefficient is set to 30% in 2005. Monthly variations are not taken into account.

Agriculture

There is one agricultural demand node per casa. The demand is calculated as the product of the surface of irrigated areas by the mean annual requirement by hectare of the casa (varying between 1094 and 2842 m3/y/ha). A coefficient of 0.7 is then applied to account for the fact that farmers generally maintain their crops under a low water stress. Irrigation is supposed to occur at the same rate from May to September. Irrigation efficiency depends on the type of irrigation system (modern or gravity). Thus, the ratio of irrigated areas that are equipped with modern devices is entered as a parameter to calculate the water losses.

Construction of the WEAP Lebanon model

After creating the different resources nodes and demand sites, transmission links are created between Demand and Supply (*Figure 2*). When a “surface water” supply exists in a casa (spring or river intake), it is preferred to groundwater for drinking water. In the model, spring intakes are represented by diversions from rivers. The maximum monthly volumes allowed to flow in these diversions are set to the actual diverted volumes.

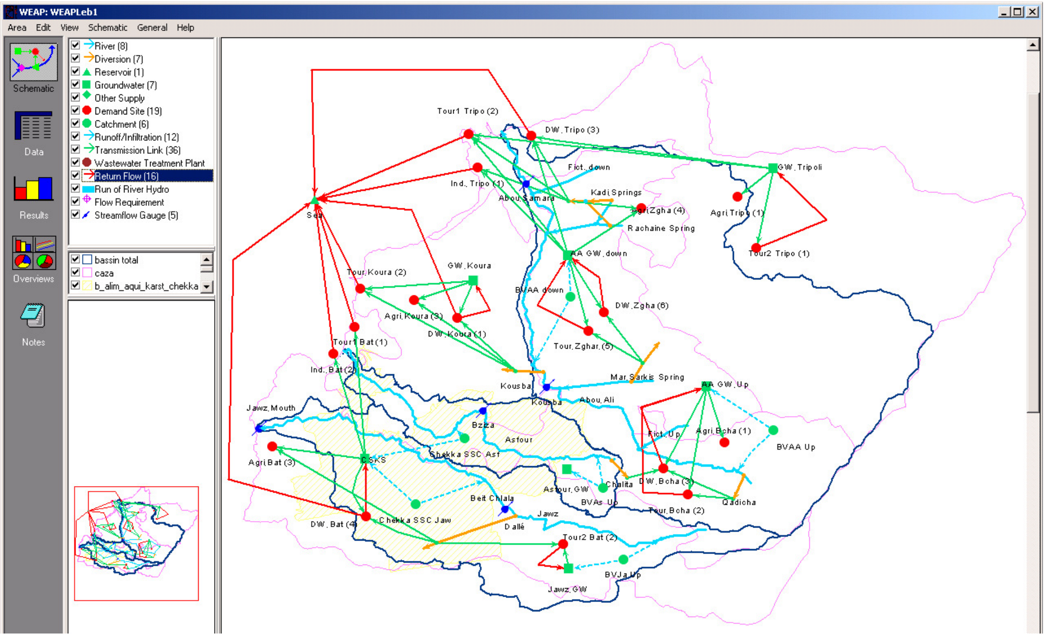

Figure 2 : Screen capture of the structure of the Chekka case study model under WEAP

Definitions of scenarios of evolution

Business as usual (BAU) scenario represents what is supposed to occur in the future considering a "simple" extension of the current trends (economic, behavioural, demographic, etc.) with no major changes. Optimistic scenario is economically and environmentally sustainable. It could correspond to a situation where a political stability has been reached in Lebanon and neighbouring countries which allows the government to place improving of living conditions, and environmental resources protection as priority issues. On the opposite, the pessimistic scenario is an extreme one (economically and environmentally) (*Table 1*).

	BAU	Optimistic	Pessimistic
Population	1.35 million	1.35 million	1.5 million
Mean DW consumption	180 l/pers./day	180 l/pers./day	180 l/pers./day
Losses in distribution network	45 %	30 %	55 %
Cultivated surfaces	Idem 2005	Idem 2005	decrease of 30 %
Modern irrigation	25 %	50 %	0 %
Mean Irrigation efficiency	62.5 %	77.5 %	55 %
Tourism filling up rate	70 %	70 %	20%
Water saving measures	20 % households with rainfall storage tanks	- 20 % households with rainfall storage tanks - 50 % households with sanitary saving devices - Pricing policy (10 % of DW saved)	None
New resources		- 30 % of wastewater reused - Exploitation of Chekka submarine springs	

Table 1 : Water demand scenarios for Chekka Case study (Lebanon)

Construction and calibration of the WEAP model

A numerical model is implemented within the WEAP software. It relies on the conceptual model of hydrological functioning of the study area and allows dynamic simulations (with a monthly time step) of river flow rates and aquifer storage. River flows are supplied both by springs and runoff from the sub catchments. River head flows are input data for the model whereas runoff is calculated according to effective precipitations. It must be noticed that the model only deals with the quantity of water; the quality aspect is not considered.
This model of water resources has been calibrated in order to try to balance the water budget using the current data (2005 is the reference year).

As already mentioned, the calibration of the WEAP numerical model was done by comparing annual observed and simulated flow rates in several points of the three rivers. The results are presented on *Figure 3*.

RIVER FLOWRATES ***(WEAP Streamflow below node)***

Million Cubic Meter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
El Abou Ali 0. Headflow	2.68	3.58	5.18	5.41	4.66	5.46	1.55	1.55	1.01	0.72	0.44	2.54	34.78
El Abou Ali 7. Kousba	*10.12*	*13.72*	*19.39*	*24.03*	*16.7*	*7.98*	*3.13*	*2.2*	*2.13*	*2.52*	*3.34*	*6.29*	*11.54*
El Abou Ali 8. Reach	20.19	16.65	16.86	10.1	8.74	9.04	2.26	2.26	1.36	0.7	5.27	16.04	109.46
Relative Error	99%	21%	-13%	-58%	-48%	13%	-28%	3%	-36%	-72%	58%	155%	-2%
El Abou Ali 15. Abou Samara	*45*	*86.12*	*39.37*	*53.27*	*65.5*	*44.32*	*13.42*	*7.61*	*4.17*	*7.66*	*7*	*100*	*473.57*
El Abou Ali 16. Reach	60.58	85.14	46.25	49.34	53.85	43.22	12.35	8.68	5.09	5.86	13.01	86.72	470.08
Relative Error	35%	-1%	17%	-7%	-18%	-2%	-8%	14%	22%	-23%	86%	-13%	-1%
El Asfour O. Headflow	0.37	0.34	0.37	0.36	0.37	0.36	0.19	0.19	0.18	0.19	0.18	0.19	3.29
El Asfour 3. Bziza	*1*	*1.19*	*1.56*	*0.89*	*0.07*	*0*	*0*	*0*	*0.09*	*0.09*	*0.08*	*0.65*	*5.61*
El Asfour 4. Reach	1.29	0.88	0.71	0.18	0.27	0.25	0.09	0.09	0.08	0	0.35	0.86	5.05
Relative Error	30%	-26%	-54%	-80%	283%				-9%	-96%	349%	32%	-10%
El Asfour 6. Reach	2.39	1.59	1.23	0.18	0.27	0.25	0.09	0.09	0.08	0	0.7	1.69	8.66
El Jawz 0. Headflow	3.31	5.27	8.7	15.91	6.93	2.82	1.47	0.96	1.07	1.31	1.75	4.64	54.14
El Jawz 3. Beit Chlala	*6.51*	*6.94*	*13.45*	*14.36*	*7.12*	*1.89*	*1.21*	*0.93*	*0.9*	*1.08*	*1.34*	*5.36*	*61.08*
El Jawz 4. Reach	6.76	7.27	9.9	15.1	6.31	2.22	0.85	0.34	0.47	0.47	2.31	7.08	59.08
Relative Error	4%	5%	-26%	5%	-11%	17%	-30%	-64%	-47%	-57%	72%	32%	-3%
El Jawz 5. Jawz Mouth	*7.97*	*8.42*	*15.27*	*16.87*	*6.62*	*0.82*	*0.06*	*0*	*0.01*	*0.25*	*0.67*	*6.72*	*63.67*
El Jawz 6. Reach	8.15	7.87	9.9	13.59	5.05	1.44	0.42	0.17	0.24	0.31	2.43	7.95	57.52
Relative Error	2%	-7%	-35%	-19%	-24%	76%	621%		2181%	22%	264%	18%	-10%

Figure 3 : Simulated and observed flowrates for the three rivers of the case study (Chekka Lebanon)

It appears that at an annual scale, the relative differences between simulations and observations do not exceed 10% which is fair for flow rates. But at a monthly scale, discrepancies are much higher. The main explanation comes from snow which is not accounting for in the model. Indeed, the snow cover acts as a reservoir which stores precipitations during winter and released water in rivers in springtime. This reservoir introduces a delay in water input. As this process is not modelled, simulated flow rates are overestimated from November to February or March, and then underestimated for the two or three following months.

A balance has been made for each hydrogeological unit of the model in order to estimate groundwater storage. The monthly variations of the volume of water in each reservoir[2] are presented on *Table 2* and *Figure 4*.

[2] GW Koura and GW Tripoli storage variations are not presented (for these two reservoirs recharge is not calculated by the model).

Monthly groundwater storage in Million Cubic Meter

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	**Total**
AbouAli Up	56,2	32,1	18,9	-11,2	-11,6	-11,9	-4,2	-4,2	-3,3	-0,9	19,1	42,1	121,0
AbouAli Down	-21,2	-55,5	-29,3	-39,2	-49,9	-39,0	-15,8	-12,1	-9,4	-727,9	719,4	-56,0	-335,9
Asfour Up	4,2	2,6	1,8	-0,4	-0,4	-0,4	-0,2	-0,2	-0,2	-0,2	1,3	3,3	11,3
Jawz Up	13,8	5,7	-0,5	-15,9	-6,9	-2,8	-1,5	-1,0	-1,1	-1,3	3,7	8,5	0,7
CSKS	30,6	19,7	14,8	0,7	-1,3	-1,8	-2,2	-2,4	-2,3	-0,7	9,5	23,4	87,9

Table 2: Assessment of monthly storage variations in each reservoir of the study area (Lebanon)

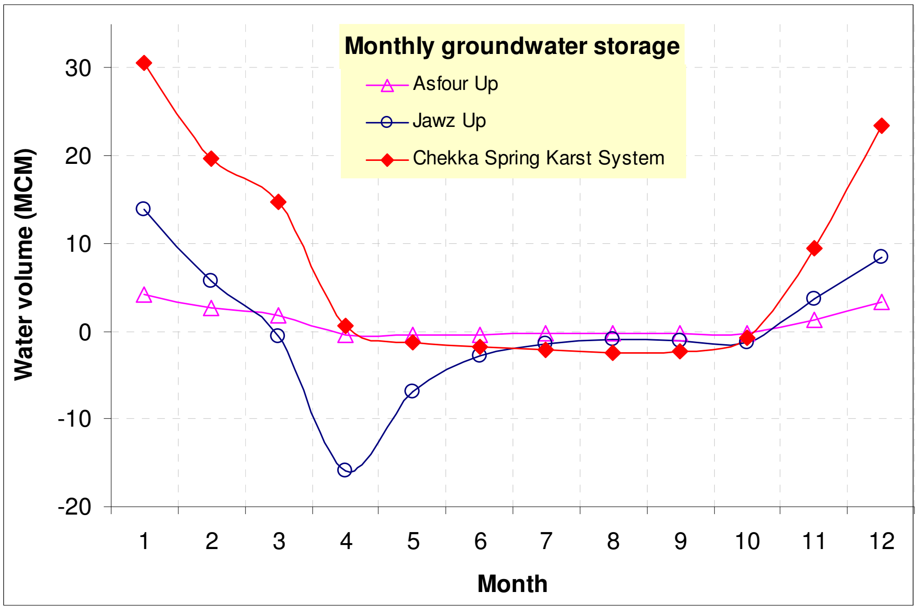

Figure 4: Monthly variations of water volume in the aquifers associated to Asfour and Jawz catchments (Lebanon)

The annual water storage in the Chekka springs karst system as calculated by the WEAP model is 88 MCM. As the karst network may be considered as well developed, it can be assumed that this water directly outflows to the Chekka submarine springs (obtained average discharge of 2.79 m^3/s). Monthly variations are important, with a maximum of 30.6 MCM in January (11.4 m^3/s) and negative storage from May to October. These results correspond to field observations made within the MEDITATE project (El-Hajj et al., 2006) as in summer time, the discharge of submarine springs is indeed very low (about 200l/s) and water is brackish (60% of seawater).

Results of Simulation of the scenarios

The WEAP Lebanon model has been run with data and parameters set to be as closed as possible to water demand scenarios. Three scenarios have been considered as explained previously: *Business as usual, Optimistic and Pessimistic.*

The total supply requirement for these three scenarios is given in the table below:

Business As Usual			Optimistic		Pessimistic	
Drinking water	165.9	53.40%	90.4	47.50%	202.5	60%
Agriculture	93.6	30.10%	75.5	39.50%	74.5	22%
Industry	50.5	16.30%	39.7	20.80%	60.8	18%
Tourism	0.5	0.20%	0.4	0.20%	0.2	
TOTAL	**310.5 MCM**		**206 MCM**		**338 MCM**	

Table 3: Lebanon -Total supply requirement in the study area in 2030 for three scenarios (Business As Usual, OPTIMISTIC and PESSIMISTIC)

Concerning the Business As Usual Scenario, the supply requirement in every node is satisfied all along the simulation. Groundwater (including spring intakes) provides almost all the water demand (98.8 %). The balance between recharge and withdrawals varies for each groundwater reservoir. Actually, for Jawz and Koura reservoirs, recharge is equal or slightly above extraction (yet it must be reminded that Koura recharge is not calculated from climate data but only estimated and set to a constant annual value of 40 MCM/year). Asfour storage slightly increases (12 MCM/year). Chekka karst system storage increases at a mean rate of 83.8 MCM/year (which in reality corresponds to the annual mean flow rate of submarine springs). On the opposite, Tripoli reservoir is over-exploited, but its recharge is not properly modelled (a constant recharge of 90 MCM/year is imposed).

Concerning the OPTIMISTIC scenario, the supply requirement in every node is satisfied all along the simulation whether the Chekka submarine springs are exploited or not. For the other groundwater reservoirs, the balance between recharge and withdrawals is generally positive: for Jawz reservoir, recharge is equal or slightly above extraction, and Asfour and Koura storages slightly increase (respectively 12 and 10.5 MCM/year).

Finally, concerning the PESSIMISTIC scenario, total water demand in the pessimistic scenario (4158 MCM in 25 years) is not so far than water demand in the optimistic scenario. Actually, drinking water needs increase is compensated by agriculture demand decrease. But as in the pessimistic scenario nothing is done to save water, the total water supply requirement is largely more important than in the other scenarios: 7050 MCM against 5367 (optimistic) and 6625 MCM (BAU). The supply requirement is satisfied in every node until 2029. From that time, a growing part of agricultural demand for Zgharta, and a growing part of all type of water demand for Tripoli can not be satisfied any more from June to October. Finally, upon 7050 MCM required only 6917 MCM of water are delivered. Groundwater (including spring intakes) provides almost all the water demand (99 %).

Conclusion

A model has been developed with WEAP to simulate the dynamic of water resources and water demand in a Lebanese case study. The lack of accurate time series data (climatic and hydrometric) and the incomplete knowledge of the regional hydrogeology (especially aquifer geometries and extends) have led to simplify the model and decrease its possibility of prediction. Nevertheless, after calibration, the model could be run to evaluate the water resources and the water demand of the area for a reference year (2005).

Regarding the water budget estimation, or the water demand calculation, the results given by the WEAP model are neither new nor different from those already brought by the work undertook in MEDITATE project concerning hydrogeological study and socio-economy analysis. But the significant contribution of the model is that it can evaluate at the same time resource and demand, and is able to balance the network at a monthly time step. For that reason, it can be used as a Water Management Support System.

During the calibration phase, it appeared that the Abou Ali catchment was not correctly modelled. Actually, effective rainfall was obviously underestimated and thus simulated river flow rates were much lower than observed data. This last point was overcome with numerical tricks (to allow running the scenarios) but basically the problem remains in the conceptual model.

Nevertheless, several ways of model improvement were suggested:

- firstly, the use of accurate and recent time series data (climatic and hydrometric),
- then a re-evaluation of precipitations (accounting for snow in the upper part of the three catchments),
- and finally hydrogeological study to improve the knowledge of the regional hydrogeology (especially aquifer geometries and extends and to define the Abou Ali hydrogeological catchment (which is probably much wider than the topographic one).

Whatever the scenario, with a water supply requirement ranging from 206 to 338 millions m^3 in 2030 and a annual water resource estimated around 700 millions m^3, there is obviously no water problem at the study area scale and at the annual scale. These global scale results hide differences between demand node and mainly between months. Thanks to the WEAP Lebanon model, risk of seasonal shortage and failure to satisfy some demand nodes, pressure points on resources and long-term over-exploitation of aquifers are highlighted. The real efficiency of management measures (such as water saving encouragements or losses reduction in distribution networks for example) is evaluated. Finally, the WMSS can be delivered to end-users and stakeholders. After a short formation, technicians and engineers can apply it to simulate and evaluate their own-defined options.

In addition to the results provided by the WEAP Lebanon model, an economic evaluation of the different management options was conducted (Aulong et al., 2008 – oral presentation WWC). The conclusions of this study are essential: complementary tools to support managers' decisions are necessary.

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