Development of Water Management Support Systems for Mediterranean Countries

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Abstract *– Water scarcity as a result of long, frequent droughts and high population growth is so severe in some of the Mediterranean countries that it threats sustainable development. Effective exploitation of existing resources, implementation of new technologies such as advanced wastewater treatment for secondary treated effluent, and desalination of brackish unutilized resources, and the development of innovative technologies such as Autonomous Underwater Vehicle (AUV) that allow the survey of certain Submarine Karstic Springs (SKS) in some of the Mediterranean countries with coastal karstic aquifers are proposed steps for the implementation of the integrated water resources management concept which will enhance sustainable development. The European MEDITATE project (INCO-MPC-2001, PL509112) aims at the development of a Water Management Support System (WMSS) that considers the previously mentioned technological developments to help improve water resources management at the basin level in four Mediterranean countries namely; Jordan, Lebanon, Syria, and Turkey. To achieve this objective, the MEDITATE project employs an integrated approach that incorporates the results of hydro-geologic modeling, the results of socio-economic study that aims at the development and comparison of contrasted water scenarios for the year 2025, and the use of the developed AUV to monitor and determine flow of SKS in three of the case studies considered in the MEDITATE which are Lebanon, Syria, and Turkey. The main objective of the developed WMSS is to help decision makers in offering them comparison and optimization tools for different scenarios with different alternatives. Mathematically speaking, the objective function of the WMSS will be to maximize demand satisfaction within the basin subject to constraints of water quantity, and water quality as well as socio-economic and environmental constraints. The developed WMSS will be customized and applied to the case studies of Jordan and Lebanon for the three contrasted scenarios developed by the socio-economic study; operating rules will be developed for the two basins in Jordan and Lebanon based on the outputs of the WMSS for the three scenarios. For the other two case studies in Syria and Turkey, guidelines to develop and implement the WMSS will be proposed.*

Keywords: Integrated water resources management, karst springs, submarine springs, water management support systems, WEAP.

1. Introduction

The scarcity of water resources in some of the Mediterranean countries as a result of frequent and long droughts is so serious that it can threat economic and social development if not managed properly. Combined in some instances with water scarcity is high population growth which increases the pressure on the already pressurized water resources which brings the need for more efficient use of the existing water resources, as well as the development of existing unutilized resources, and the search for new resources. Political instability in the region in some instances has contributed to adding an instantaneous and huge stress on the very limited water resources for some countries like Jordan. In water scarce countries, the implementation of Integrated Water Resources Management (IWRM) that takes into consideration water availability in terms of quantity and quality, socio economical and environmental factors as well as political circumstances, is a key issue in alleviating the impacts of water scarcity both in the short and long runs. It also provides the decision makers with some flexibility in dealing with the events of expected and unexpected water shortages.

Decision Support Systems (DSS) which is an alternative term to the Water Management Support System (WMSS) used in the MEDITATE project, are numerical tools developed to facilitate the implementation of Integrated Water Resources Management. They generally involve at least two building blocks among integrated stand alone models such as hydrological models, GIS, data management systems and decision support modules which are tools that utilize artificial intelligence and scenario techniques (Denzer, 2005). Literature review shows that the term DSS is used to describe a large variety of systems and tools.

In three of the case study basins, namely: Lebanon, Syria, and Turkey the MEDITATE project involves detailed surveys of unutilized submarine springs using the developed Autonomous Underwater Vehicle (AUV) to determine their suitability as an additional water resource in terms of quantity and quality. The case study of Jordan is different in the sense that no submarine springs are involved, however, treated wastewater and desalination of brackish water are viewed as additional resources that should significantly contribute to solving the problem of water scarcity in Jordan.

The MEDITATE project main objective is the development of a Water Management Support System (WMSS) that aims at the optimum allocation of the available water resources to different consumers at the basin level subject to constraints of water quantities, water qualities, demand priorities, as well as socio-economic, and environmental constraints. The developed WMSS will be customized and applied to the case studies in Jordan and Lebanon which will help identify short and long term measures to improve water management practices in these basins. For the other two case studies in Syria and Turkey, guidelines for the implementation of the WMSS will be developed.
After a brief presentation of the four case studies considered in the MEDITATE project, this paper presents the methodology and the work in progress to develop and implement the WMSS.

2. Case studies

2.1 Amman Zarqa Basin, Jordan

Amman-Zarqa Basin (AZB) in Jordan is the most utilized and developed basin among other groundwater basins in the country. AZB comprises the greater Amman, Dhuleil, upper Zarqa, Baqa'a and Jarash areas. The average rainfall in the basin is 250 mm/year. It drains a total area of 4094 km^2, 3739 km^2 of which are within Jordan, and 355 km^2 are within Syria. The area of the basin makes about 4% of Jordan's total area. However the population in the basin was about 3.2 million for the year 2003 according to the Department of Statistics which is about 58% of Jordan's population for that year. The safe yield of the aquifers in the basin is estimated at 88 MCM per year which is about 32% of Jordan's renewable water resources (ARD, 2001). Due to the high population in AZB, groundwater resources in the basin are over exploited to satisfy the increasing demands for the different sectors. AZB contains over 800 wells used for different purposes, domestic, agricultural, industrial, and touristic. The agricultural demand in the basin for the year 2005 made about 50.8% (MWI, 2004) of the total basin demand which is the highest among other demands, domestic, industrial, net losses and touristic. The main surface water within the basin is the Zarqa River, the annual flow of which is about 63 MCM (Multilateral working group on water resources, 1998). During summer, Zarqa river flow consists mainly of the effluent of As-Samra wastewater treatment plant which is the largest wastewater treatment plant in Jordan. As-Samra treatment plant receives about 80% of the wastewater generated in Amman and Zarqa. The influent to the plant is now about three folds of its design flow, which makes its quality much below the standards for the secondary treatment which barely makes it suitable for restricted irrigation. However the plant is under upgrade to a mechanical system the effluent of which should meet the standards of secondary treatment which will result in a big improvement of the quality of the Zarqa River. The amount of treated wastewater effluent in AZB was about 95 MCM for the year 2005 (MWI, 2004). It is projected that treated wastewater effluent in AZB will be about 163 MCM for the year 2020 (MWI, 2004) which is about twice the safe yield of the aquifers within the basin. The relatively huge amount of treated wastewater effluent in AZB brings the need for better utilization of this resource. If the quality of this effluent can be brought to a level where it becomes suitable for unrestricted irrigation, the decision maker will have more flexibility in managing the groundwater resources in the basin to stop over abstraction. The basin also includes about 150 springs the flow of which is about 50 MCM per year. Most of these springs are exploited for domestic, industrial or agricultural purposes. The fact that large proportion of Jordan's population live within 4% of Jordan's area, in AZB, with increasing demands as a result of population and economic growths, makes the implementation of integrated water resources management crucial to the sustainability of the development and economic growth within this basin.

2.2 Chekka Bay area, Lebanon

The Chekka area in Lebanon is located 62 km north of Beirut. This area includes karst submarine springs which are located between 25 and 1500 m from the shore. This group of submarine springs is the discharge area of the karst aquifer that takes place within the Cenomano-Turonian limestone which is 600 m thick. Senonian marls cover these layers. The karst aquifer is consequently a captive aquifer. The catchment area of the Chekka submarine springs, called Chekka-Rachine catchment, covers an area of about 700 km^2. It is bounded by El Ayoun from the north, by the contact between Turonian limestone and Tertiary layers from the west and by Nahr El Joz valley from the south. The karst submarine springs in the Chekka area are viewed as a potential important new water resource that should be investigated to satisfy the growing demand on fresh water in this area. In the framework of the MEDITATE project, detailed surveys of these unutilized submarine springs using an Autonomous Underwater Vehicle (AUV) developed by the LIRMM (www.lirmm.fr/) have been done to determine their suitability as an additional water resource in terms of quantity and quality.

The alimentation basin of the Chekka karstic aquifer is not yet well delimited. It covers parts of the limestones of three rivers watersheds, which are Nahr abu Ali, Nahr el Asfour, and Nahr el Jaouz, of which, Nahr abu Ali is the only one that has flow year around. Water losses take place along the rivers which recharge the aquifer and contribute to the karstic springs flow.

In the great region, Lebanon is one of the countries with the most abundant water resources. Nevertheless, the water sector in Lebanon suffers from technical, administrative, and other constraints limiting the access to water and creating socio-economical impacts (El-Fadel et al., 2002). The high population growth which is about 1.76% per year, the increasing urbanization, the economic development including touristic activities, the inefficient supply system as evidenced by the high losses which are estimated between 30% and 50%, and the lack of efficient wastewater treatment plants lead to both water resources depletion and degradation of the water quality.

2.3 Bassie area, Syria

The study area in Syria is called Bassieh, which is part of the coastal basin. It is bounded from the west by the Mediterranean Sea and extends from As-Sinn spring near Banias north to Al-Marquieh River south, covering an area of about 880 km^2. The study area makes the northern part of Tartous governorate. It occupies more than one third of the governorate area which includes three districts, namely; Banias, Al A'nazah and Qadmous. The study area is characterized by plenty of sub-vertical tectonic faults of different ages, having different orientations and shifting amplitude of block from 20 m to 400 m. The largest fault line in the study area runs along Marquieh River, the mainstream of which runs along the fault line. The morphology of the study area varies widely from place to place; the main features are the coastal alluvial plain, and the low basaltic hills along the coast near Banias.

Springs are the main water resource in the study area, which provide about 63% of the water supply. The main springs in the study area are As-Sinn which has the largest discharge, Naba Aldeba, Al-Shaman, Aldiron, and Naba Goret Alhasan, the discharges of which are 9432, 600, 425, 290, and 200 m^3/hr respectively. Groundwater provides 36% of the water supply in the study area, the remaining 1% of the water supply is provided by Ballouran dam which is located in Lattakia governorate, the release of which is about 290 m^3/hr. The major water consumer in the study area is agriculture which consumes about 90% of the available water resources in this area, domestic water use is about 9% of the water resources in the study area, the remainder 1% is used by the industry.
Since last decade, a dry continental climate has prevailed in the eastern Mediterranean basin, leading to substantial decrease in average precipitation. The accelerated population growth aggravates the water demand versus water resources problem in Syria. Several basins face shortage in water supply, particularly, Damascus basin. Therefore, authorities are looking for alternative resources. The coastal area with the important karstic reservoir and submarine springs is considered a potential resource to solve the problem of the increasing water demand in Syria.

The undersea discharge of groundwater has been well known in the region since the days of Romans. Water from these springs was collected by a boat, using a lead funnel and leather tube, and then transported to Tyre in Lebanon and Arados in Syria as a source of fresh water (Ghannam et al 1998; UNESCO 2004). Several investigators have reported the occurrence of many submarine springs off the coast of Syria, some of which are of fairly high discharge. Submarine springs' discharge from Bassieh Gulf was estimated based on hydro-geological balance at one billion m^3/year. Using the developed AUV will allow more accurate estimate of the discharge of these submarine springs which will result in improving our knowledge about the reliability of these submarine springs as a water resource.

2.4 Gökova Bay, Turkey

Gökova Bay which is one of the famous touristy resorts in south western Turkey is the study area which exhibits well developed karst aquifer with great diversity of management and environmental problems. Geographically, the study area is in the West Taurus Mountains in the Western Mediterranean region of Turkey. The lineaments detected by satellite images, extends in the N0-50^0E, and N0-90^0E and N0-50^0W directions. Moreover, karstic formations (sinkholes and uvalas) are numerous in the area between the north of Oren and the north of Akbuk, and along the SW-NE of Mugla and the upthrust zone. Their sequence is generally in the NE-SW and NW-SE directions. The karst system covers an area of about 1200 km^2. The karst aquifer is the main fresh water supply in the study area. Tourists are the main water consumer in the study area.

The springs of Gökova discharge from the coastline between Akkaya-Akbuk in the north of Gokova Bay. Five groups of springs are found in the area, they mainly discharge along fault lines within carbonate rock masses of Mesozoic age. Apart from the coastal karst springs, several submarine springs are also found in the area. Salinity and conductivity anomalies were recorded at the sea between the points where Azmak and Akcapinar creeks reach the sea as a result of the direct contct between the karst aquifer and sea water at many places (DSI, 1992; Eroskay et al., 1992). The development and sustainability of Gökova Bay as a touristic resort depends to a great extent on the availability of fresh water resources. The use of the AUV will provide a reliable tool to gain better knowledge of the discharge and qulaity of the submarine sprigs in the study area. The study areas for the four catchments in Jordan, Lebanon, Syria and Turkey is shown in Figure 1 (Dorfliger et al. 2006).

Figure 1. Location of test sites of MEDITATE project in eastern part of the Mediterranean basin

3. Methodology

The MEDITATE project utilizes an integrated approach for the development of the WMSS. It integrates outputs from different modules into the developed WMSS:

- Hydro-geologic modelling at the catchment level provides the safe yield of the available ground and surface waters with their temporal and spatial distributions. For catchments with Submarine Karst Springs (SKS) in Lebanon, Syria, and Turkey, the developed (AUV) will be used for the monitoring and the determination of the discharges of these springs.
- The socio-economic study provides qualitative information about the driving forces on water demands for the different sectors which will be quantified and used in the development of the three scenarios for the year 2025 for which the developed WMSS will be run. Interactive water vision workshops were held at the four case studies sites in the year 2005, the results of which are given in (Ker Rault et al., 2006). Stakeholders that represent water users and a wide range of people concerned with the local water management have participated in these workshops. Stakeholders identified the different driving forces on water use as well as the trends of descriptors and indicators for the three scenarios considered in the MEDITATE project until the year 2025.
- As cost is one of the primary factors in deciding which measures should be implemented in a specific basin, Cost Effectiveness Analysis (CEA) that aims at determining the cost per cubic meter of water will be performed for the measures to be implemented in each basin. According to the Asian Development Bank (1998), these measures can be technical such as capture and desalination of Submarine Karstic Springs, construction of dams, advanced wastewater treatment of secondary treated effluent, etc., or policy related such as reduction of water consumption by introducing metering devices or by carrying out public awareness education programs to promote efficient water use, etc.. Cost effectiveness analysis will include all types of costs such as, capital cost, energy cost, personnel cost, chemicals and materials cost, transportation cost, etc. The following stepwise procedure is implemented in the development of the WMSS:

3.1 Definition of the WMSS objective

The first and most important step in the development of the WMSS is the definition of its objective based on the users' needs and water availability. Due to the limited water resources in the basins under consideration and the need for more efficient use of the existing ones, the WMSS will be formulated to maximize demand satisfaction in the basin subject to constraints of water availability, water quality, demand priorities, as well as socio-economic and environmental constraints.

3.2 Identification and ranking of criteria for supplying water

In developing the WMSS, it is important to identify and rank the different criteria for supplying the water to the different consumers within the basin. Criteria identified for supplying the water in the case studies within the MEDITATE project are in addition to water quantity, water quality, socio-economic, environmental, demand priorities, and cost. All sources within the basins are classified whether they are suitable for domestic, agricultural or industrial use. Sources suitable for irrigation are further classified whether they are suitable for restricted or unrestricted irrigation based on their quality. Water quality criteria that have negative environmental impacts are taken into consideration. i.e. treated wastewater should be of certain quality in terms of Total Dissolved Solids (TDS) to prevent accumulation of salt in the soil which affects plant productivity, Fecal and Total Coliform Counts should not exceed certain number to protect the health of the farmers who get in touch with the treated wastewater and to protect the health of children who live in the vicinity of agricultural areas irrigated by wastewater, and nitrogen as NO_3 should not exceed certain limit to prevent groundwater pollution by nitrate when irrigated areas overlay a groundwater aquifer. Cost is another important criterion that will be taken into consideration, in case several alternatives are available to satisfy a certain demand, the supply of the lowest cost will be considered first. CEA will be run to rank the different supplies according to their costs. For high quality sources, priorities for satisfying the different demands will be set. i.e. if a source is suitable for domestic use, all domestic demands should be satisfied first from this source before any irrigation demand can be satisfied. The set of criteria and priorities will be expressed mathematically within the WMSS as a set of constraints.

3.3 Model selection

The question rapidly aroused is whether a generic DSS model should be used in MEDITATE or a specific software should be developed? This question was previously addressed in other European projects related to water management such as water strategy man project (2003) with various answers. Within the MEDITATE project, it has been decided to use a generic DSS model. Regarding the scenario evaluation and the decision part of the WMSS, the objective function and the set of constraints represent a Linear Programming (LP) problem that can be solved by different computer models, either generic or specific. However, generic models have the advantage of providing convivial Graphical User Interface (GUI) and Graphical Information System (GIS) features, and facilities to integrate physical, socio-economical and decision models (if not embedded). Figure 2 below shows the different components of a DSS.

In order to choose a generic DSS model that can be adapted to the project's needs and objectives, a dedicated review was conducted. The review focused on several points of interest for the MEDITATE project, namely:

- the different components of the model,
- the water supply and the water demand modelling capabilities that can possibly incorporate site specific supply and demand functions,
- the ability to handle both surface water and groundwater,
- the way water quality problems can be addressed,
- the possibility to compare various water policy scenarios, and
- technical, and commercial aspects.

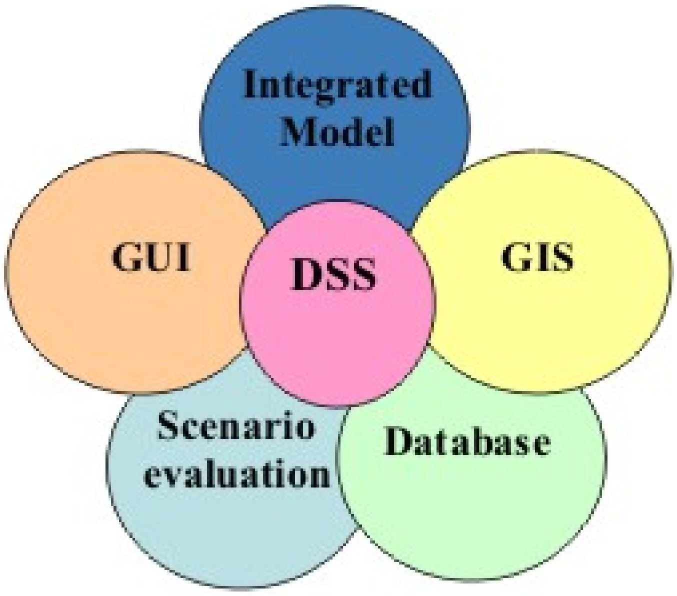

Figure 2. The different components of a DSS

3.3.2 WEAP model: a short description

The Water Evaluation and Planning model WEAP, (Yates et al., 2005) which is developed by the Stockholm Environment Institute was chosen. WEAP utilizes an optimization approach to allocate water to different demand sites within a basin under water scarcity conditions. Examples are given in the literature of concrete applications of this model (Raskin et al., 1992; Lévite et al., 2003).

WEAP model simulations are built as a set of scenarios, where time steps can range from one day to one week or one month with a time horizon from as short as one year to as long as 100 years. This is interesting to simulate the long term trends and evolutions.

WEAP is designed as a comparative analysis tool: a base scenario is developed and then alternative scenarios are compared to this base scenario according to sets of criteria. In the framework of the MEDITATE project, three contrasted scenarios will be simulated for the year 2025 based on the results of the Water Vision Workshops (Ker Rault et al., 2006) which are:

- Business As Usual scenario, which is to be considered the base scenario, and the reference for comparison,
- Potential Sustainable Scenario, and
- Potential Unsustainable Scenario.

WEAP data objects and the model framework are graphically oriented to allow the spatial referencing of watershed attributes (e.g. rivers and groundwater systems, demand sites, supply sites as springs or boreholes, wastewater treatment plants, political boundaries, etc.). The screenshot from WEAP21 shown by Figure 3 shows how demands and water resources are created in a simple watershed example. Each demand site is connected to one or more supply sites by transmission link. The watershed can be divided into a number of irregular sub-watersheds based on natural boundaries (e.g. watershed hydraulic boundaries, climatological regions), or land-use categories, or even combinations of both.

Another interesting feature of the WEAP21 model is that it provides flexibility in how data is structured? Data structure can range from highly disaggregated structure to highly aggregated structure (Yates et al., 2005). For example it can accept detailed agricultural demand features such as water needs for various crops if available. However, if these demand features are not available, a global water demand estimate can be used for the whole irrigated area.

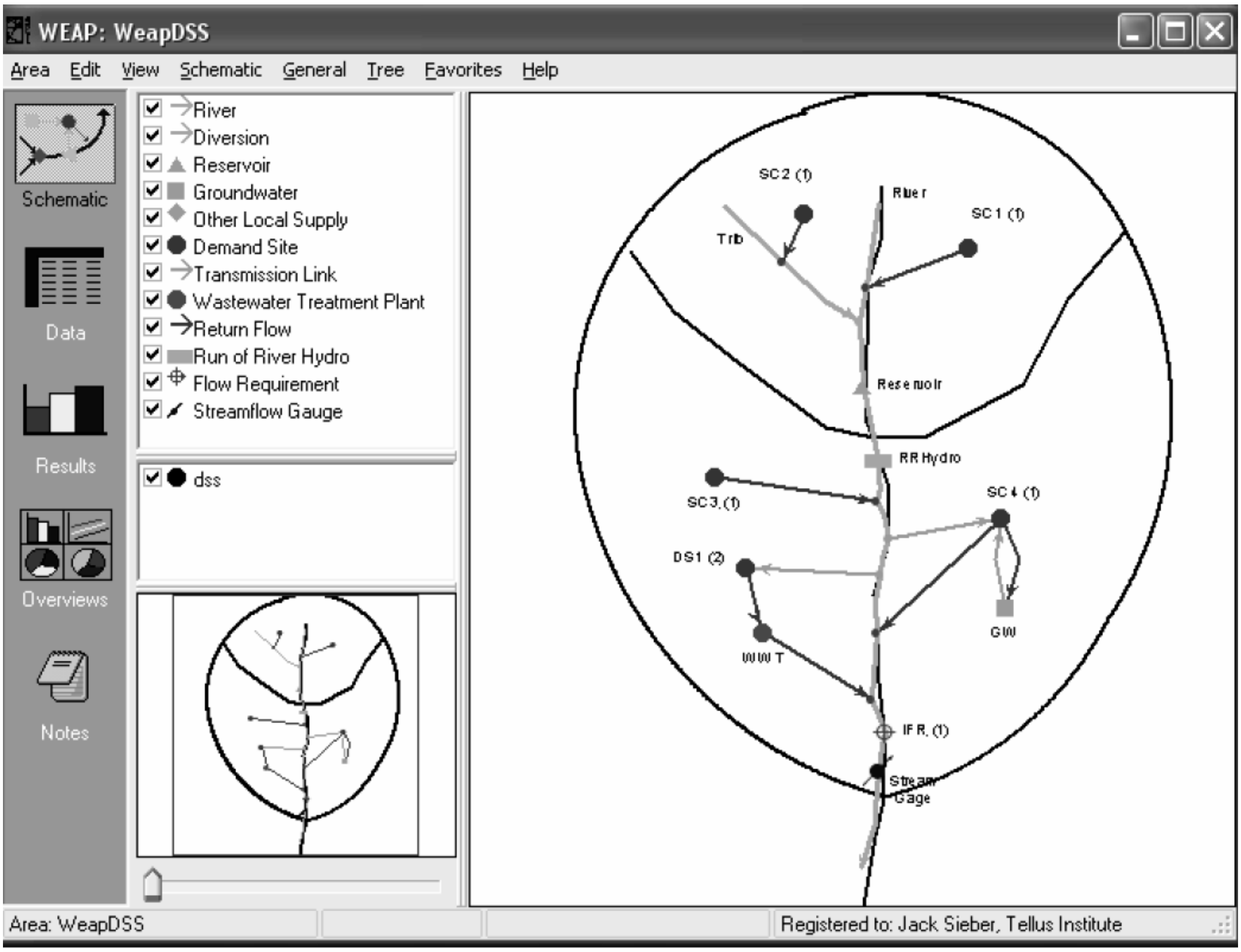

Figure 3. An example of a simple watershed, using the WEAP21 Graphical User Interface (Yates et al., 2005)

3.4 Identification of the data needs to develop the data base

Data needed to run a specific model depends on the model itself and the problem under consideration. For the case of the WMSS developed in the MEDITATE, data needs include knowledge of all water supplies in the basin including their spatial distribution, quantity and quality. Sources are classified based on their quality as suitable for the different uses which are domestic, agricultural, industrial, and touristic. Some uses include sub categories; agricultural sources are classified as suitable for restricted irrigation or for unrestricted irrigation. Knowledge about all demand nodes within the basin is also necessary, demand nodes are classified as domestic, agricultural, industrial and touristic. Data about transport systems within the basin such as pipes and channels are also important. The data needed for the case studies of AZB in Jordan and Chekka Bay area in Lebanon have been collected and stored in GIS data base.

3.5 Mathematical formulation of the WMSS

The objective of the WMSS and the set of criteria for supplying the water within the basin are expressed mathematically as an objective function subject to a set of constraints. The objective function is to maximize demand satisfaction.

3.5.1 The WEAP allocation module: demand priorities, supply preferences and Equity Group

In WEAP, the starting point in the management analysis is the definition of the allocation rules by the user. Each demand node is assigned a user-defined priority expressed by an integer from 1 (highest priority) to 99 (lowest priority). Each demand is then linked to the available sources, which are also assigned preferences expressed by integers from 1 to 99.

In WEAP, a standard linear program is used to solve the water allocation, problem. The objective function is the maximization of demand satisfaction subject to constraints of supply preferences, demand priorities, mass balance, and other constraints such as water quality, and minimum flow requirements. WEAP also calculates the cost of supplying water.

Demand sites with Priority one are members of Equity Group one, demand sites with Priority two are members of Equity Group two, and so on. The allocation algorithm in the WEAP model allocates water to demand nodes with demand priority one first, during this process, demand nodes with demand priorities two and lower are suspended. Once water is allocated to demand nodes with demand priority one, demand nodes with priority two are activated.

3.5.2 Allocation algorithm in WEAP

The general form of the allocation algorithm is given by Figure 4 which shows the objective function and the set of constraints. Where *p* is demand priority, *f* is supply preference for each demand *k*, of *N* total demand sites. The constants $D_k^{p,t-n}$ are determined for each demand site *k* with priority *p*. The $x_{j,i}^p$ are flows from nodes *j* to node *I* with priority *p*, S_i^t are the reservoir storages at site *I* for time *t*, C_p is the total coverage for priority *p*, and c_p^k is the percent coverage for individual demand sites.

3.6 Customize and run the WMSS for the two case studies in Jordan and Lebanon

The objective function which was defined on the bases of the users' needs and water availability, the constraints which were set based on the different criteria and their ranking, and the collected data will be put in a format suitable to run the WEAP. The WMSS will be run for the three contrasted scenarios identified by the stakeholders during the Water Vision workshops held in 2005 (Ker Rault et al., 2006), for the two case studies in Jordan and Lebanon. Based on the output of the WMSS, rules to supply the water for the different scenarios will be derived and set. For the other two case studies in Syria and Turkey, guidelines for the development and implementation of the WMSS will be set.

3.6.1 Chekka Bay area, Lebanon case study

The following challenges are identified for the development of the WMSS for the Lebanon case study.

1. First of all lies on the degree of knowledge of the functioning of the Chekka karstic aquifer. This includes the delimitation of its recharge area, the modes of recharge and their quantification (by the rainfall, by the losses along the rivers, etc.). This point is important as it constitutes an element for the quantification of future alternative water resources.
2. Chekka aquifer is characterized by a karstic functioning. Will we be able to render the associated specific relation between surface and groundwater with the WEAP surface water and groundwater modules?
3. Third is linked to the availability of the data to estimate both the water demand (for example, for agriculture, plants water requirements, irrigated surfaces, irrigation process and eventually associated water losses, etc.) and the water supply (spring flows, river flows, etc.).

For each $p = 1$ to P for each demand priority

For each $f = 1$ to $F \in (D_k^{p,t-n})$ for each supply preference to demand, k

maximize (Coverage to all demand sites $k \in N$ with priority p)

$Z = C_p$

subject to

$\sum_{j=1}^{n} x_{j,i}^{p} - \sum_{r=1}^{m} x_{i,r}^{p} + S_i^{t-1} = S_i^{t}$ mass balance constraint with storage for node i to node r

$\sum_{j=1}^{F} x_{j,k}^{p} = \mathbf{D}_k^{p,t-n}$ demand node constraint for demand k from j sources

$\sum_{j=1}^{F} x_{j,k}^{p} = \mathbf{D}_k^{p,t-n} * c_k^p$ coverage consraint for demand k from j sources

$\sum_{j=1}^{m} x_{j,k}^{p} \geq \mathrm{D}_k^{p,t-n} * c_k^p$ coverage constraint for ifr and reservoirs k from j sources

$\mathrm{c}_k^p = C$ equity constraint for demand site k with priority p

$\mathrm{c}_k^p \geq C$ equity constraint for ifr and reservoirs with priority p

$0 \leq \mathrm{c}_k^p \leq 1$ bound for demand site coverage variables (not ifr or reservoirs)

$x_{i,l}^{>p} = 0$ for demand sites l with priority $> p$

$x_{i,k}^{p} \geq 0$ for demand sites k with priority $= p$

$x_{i,k}^{f} \geq 0$ for demand sites k with preference $= f$

$x_{i,k}^{>f} = 0$ for demand sites k with preference $> f$

Solve LP, then

1. Evaluate shadow prices (h_k^p) of each equity constraint, is $h_k^p > 0$?
2. If so, set $x_{j,k}^{p}$ and c_k to optimal values from solution
3. Remove equity constraints with $h_k^p > 0$

Next iteration for current priority, p

4. Set $x_{i,k}^{f}$ to optimal values

Next f

Next p

Figure 4. Allocation algorithm in WEAP (Yates et al., 2005)

4. The objectives in water management expressed in Lebanon for horizon 2030 are (i) the satisfaction of the water demand (primarily for households, in summer as well as in winter), and (ii) minimum flow requirements in some strategic sections of the principal rivers (to be defined). To reach these objectives, some measures can be envisaged, acting ever on the water supply or on the water demand: building of dams and hill lakes, exploitation of the submarine springs, desalination of brackish water, use of treated waters for irrigation, modification of the irrigation systems (close up of the open canals, etc.), modernization of the water supply network to limit the percentage of losses, water pricing to encourage saving, and to raise public awareness about water scarcity. The challenges are to translate these objectives and measures into the WEAP formulation, to be able to test (and then compare and classify) the effects and the costs of these measures.

4. Results and Conclusions

A Water Management Support System (WMSS) that aims at maximizing demand coverage under water shortage conditions will be developed and implemented for two of the four case studies considered in the MEDITATE which are Jordan and Lebanon. The WMSS incorporates output from the hydro-geologic modeling, and from the socio-economic study. The WMSS will be run for the three contrasted scenarios ("Business As Usual", "Potential Sustainable Scenario", and "Potential Unsustainable Scenario") identified by the stakeholders during the Water Vision workshops which were held in the four case study sites during 2005. Based on the output of the WMSS, rules for supplying the water within the basin will be derived and set. For the other two case studies in Syria and Turkey, guidelines for the development and implementation of the WMSS will be set.

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References

Associates in Rural Development Inc. (ARD) (2001). The Water Resource Policy Support activity. A report submitted to the Ministry of Water and Irrigation, Jordan.

Asian Development Bank (1998). Handbook on the Economic Analysis of Water Supply Projects, Economics and Development Resource Center.

Denzer, R. (2005). Generic integration of environmental decision support systems -state–of- the- art. Environmental Modelling & Software, 20,1217-1223.

Dörfliger, N., Bakalowicz, M., Jouvencel, B., Najem, W., El Hajj, A., Al Charideh, A.R., Alfares, W., Fayyad, M., Al Omari, A., Comair, F., Ekmekci, M., Levant, T., Jeffrey, P., Ker Rault, P., Malfeito, J. (2006). Innovative technologies for integrated water management: karst submarine spring and water reuse as alternative water resources. In International Congress, Integrated Water Resource Management and Challenges of the Sustainable Development, Marrakech, 23rd-25th May 2006, University Cadi Ayya, 6pp.

DSİ (1992). Report on the Karst Hydrogeology and the Development of Muğla Gökova and İskele Springs. Final Report. Dept. of Groundwater and Geotechnical Services, State Hydraulic Works (DSİ), Ankara, (in Turkish)

El-Fadel, M., Zeinati, M., & Jamali, D. (2002). Water management in Lebanon: Institutional capacity and policy options. Water Policy, 3(5), 425-448.

Eroskay, O., Gözübol, A.M., Gürpınar, O., & Şenyuva, T. (1992). Geologic and Hydrogeologic Investigation of the Muğla-Gökova and Milas-Savran Springs. Final Report. Dept. of Groundwater and Geotechnical Services, State Hydraulic Works (DSİ). Ankara, (in Turkish)

Ghannam, J., George, M., Ayoub, G., & Acra, A. (1998). A profile of the submarine springs in Lebanon as a potential water resource. Water International, 23, 278-286.

Ker Rault, P., Bouzit, M., Jeffrey, P., Salman, A., AL-Karablieh, E., Attila, O., & Yüzereroglu, S., (2006). Application of a participatory foresight methodology at river basin scale in Jordan and Turkey. Proceedings of the International Congress, Integrated Water Resource Management and Challenges of the Sustainable Development, Marrakech, 23rd-25th May 2006, University Cadi Ayya,

Lévite, H., Sally, H., & Cour, J. (2003). Testing water demand management scenarios in a water-stressed basin in South Africa: application of the WEAP model. Physics and Chemistry of the Earth, 28, 779-786.

Ministry of Water and Irrigation (2004). National Water Master Plan, Jordan.

Moriarty, P.B., Shraideh, F., & Haddad, F. et al. (2005). Scenario building in local-level water resource management – experience from the EMPOWERS project with reference to a case study in Jordan, EMPOWERS regional Symposium: End-Users Ownership and Involvement in IWRM, 13-17 November 2005, Cairo, Egypt.

Multilateral working group on water resources (1998). Overview of the Middle East Water Resources, a report published at the following internet site (http://exact-me.org/overview/index_pdf.htm).

Parker, P., Letcher, R., & Jakeman, A. et al. (2002). Progress in integrated assessment and modeling. Environmental Modeling & Software, 17, 209-217.

Raskin, P., Hansen, E., & Zhu, Z. (1992). Simulation of water supply and demand in the Aral Sea Region. Water International, 17, 55-67.

UNESCO (2004). Submarine Groundwater Discharge. Management Implications, Measurements and Effects. IHP-VI, Series on Groundwater No.5, ICO Manuals and Guides No.44.

Water strategy man project (2003). Report on Models, Tools and DSS for water management. Deliverable 10. Contract n° EVK1-CT-2001-00098.

Yamout, G., & El-Fadel, M. (2005). An optimization approach for multi-sectorial water supply management in the greater Beirut Area. Water Resources Management, 19, 791-812.

Yates, D., Sieber, J., Purkey, D., & Huber-Lee A. (2005). WEAP21-a demand-, priority-, and preference-driven water planning model: part 1, model characteristics. Water International, 30, 487-500.