International Congress on Environmental Modelling and Software

3rd International Congress on Environmental Modelling and Software - Burlington, Vermont, USA - July 2006

Jul 1st, 12:00 AM

Development of an Integrated Decision Support System for Water Quality Control in the Upper Litani Basin, Lebanon

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Abstract: Compared to the limited water supply in the Middle East, Lebanon is perceived to be a water rich country. Yet, it faces a growing water supply problem due to many factors including increases in demand, inadequate investment in infrastructure, and deterioration of water quality. Being the foremost water resource in Lebanon, the Litani River is at the center of several major water supply and irrigation schemes. However, the river water quality is severely impacted by the current practice of releasing untreated sewage into its water body, specifically in its upper basin which is home to about half a million inhabitants. This problem has prompted government and non-government agencies to consider the installation of several wastewater treatment facilities. This paper reports on the development of an integrated Decision Support System (DSS) for the Upper Litani Basin to be used by decision makers to assess the current status and explore potential solution alternatives. The DSS was developed based on the Water Evaluation and Planning (WEAP) model. The GIS-based interface of WEAP facilitated disaggregate representation of individual communities, wastewater treatment plants, water supply intakes and return flows and the river system. For a given simulation run which could span several years, the DSS calculates and routes sewage loads from each community to the river system or treatment plants. Water quality routines are used to estimate pollutant concentrations in the river. Concentrations and volumes of effluents from wastewater treatment plants are calculated based on given plant design specifications.

Keywords: Decision support system, Water Quality, Modeling, Geographic information systems, Lebanon

1. INTRODUCTION

With mountains paralleling most of its Mediterranean coast, inducing significant precipitation during the winter, and maintaining several perennial rivers and springs, Lebanon is endowed with rich water resources in comparison to the water deprived nations of the Middle East. However, topographical and climatic conditions have imposed a natural disparity in the distribution of water resources across the country, with the semi-arid interior and southern regions lagging in meeting their rising water demands. With an area constituting over 60% of Lebanon's 10,500 km^2 and a 30% of Lebanon's 4.5 million, the economy of this region is agro-based and consequently sensitive to the highly variable natural water supply. This has led to several national initiatives to support the socio-economical development of the region through planning major water diversion and supply schemes.

The majority of these schemes are based on diverting water stored in the man-made Lake Qaraoun that has impounded the Litani River since 1960. The Litani River is the largest of all Lebanese rivers in terms of the size of watershed, length and annual flow. It has been described as the Nile of Lebanon as it rises near the ancient city of Baalbek (Figure 1), transverses through the heart of the country, and drains over one-fifth of its area into the Mediterranean. The Litani River Authority (LRA) was formed in 1954 to facilitate the integrated development of the Litani River Basin, [LRA 2004]. Shortly after its formation, the LRA engaged in a massive hydroelectric development project that tapped the 850 meter head potential between Lake Qaraoun and the Mediterranean. This development has brought about major hydrological changes to the Litani River Basin, where the flows from its upper reaches above Lake Qaraoun, referred to as the

Upper Litani Basin (ULB), are diverted through a system of tunnels, ponds and plants, to meet the Mediterranean several kilometers north of its original natural tailwater. These changes have resulted in the effective hydrological separation between the ULB and the Litani lower reaches.

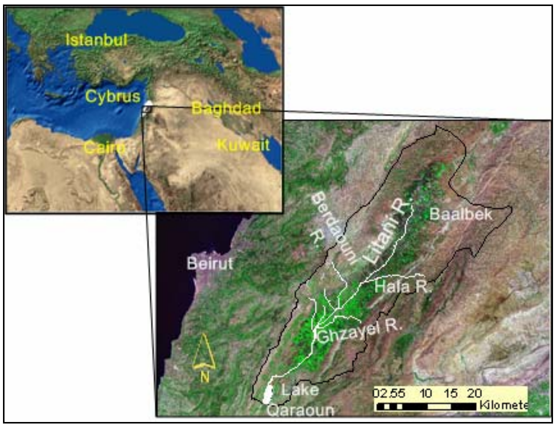

Figure 1. The Upper Litani Basin.

The advent of a protracted civil strife in the 1970s followed by a prolonged occupation in the 1980s that lasted into the 1990s, have plunged the country into disarray, freezing development and investment in infrastructure. The subsequent return to normal conditions has encouraged the LRA to initiate several major water diversion projects from the ULB worth hundreds of millions of US dollars [LRA 2004].

The viabilities of these projects and any future water resources development in the ULB are increasingly threatened by a wide scale and intense deterioration of the ULB water quality caused mainly by the relentless release, of untreated domestic wastewaters, directly into the river. The situation has reached such an alarming stage that the Litani River has been described as an "open-sky sewer" by the Lebanese Ministry of Environment [Kaskas and Awida, 2000].

This paper reports on the development of a decision support system (DSS) to help decision makers to simulate and assess alternative water quality control policy options. Developed based on the Water Evaluation and Planning (WEAP) model, the ULB DSS is used to assess two proposed wastewater treatment plans.

2. WATER POLLUTION IN THE ULB

The 1600 km^2 ULB is home to about 500,000 inhabitants with a workforce mostly engaged in agricultural activities or employed in the services, food processing, and the public sectors. Although most of the population is served by water supply networks fed by springs that dot the upper reaches of the basin, most of the wastewater is released untreated into the river network, with the rest sent to septic tanks. These activities along with leaching from expanding agricultural land and poorly managed landfills have led to wide scale water pollution in the basin.

The extent and severity of water pollution in the ULB have been confirmed by the findings of a recent environmental assessment study funded by the USAID [BAMAS 2005a and 2005b]. Figure 2 shows the measurements of counts of Fecal Coliform (FC) (CFU/ 100 mL) at several locations across the basin for the winter and summer periods. The FC is a microbiological indicator used to identify pollution caused by sewage wastewater. Drinking water standards forbid the presence of FC since it is highly detrimental to human health. Figure 2 show extremely high FC values especially in the summer, with values in the hundreds of thousands at some locations. The situation is of concern considering that the study and other previous studies [FORWARD 2003] have reported that many farmers tap into these dangerously bacteria-invested waters during the rainless summer season. Not only is the practice highly risky to local users, but could also have dire consequences to the health of consumers of produce from crops irrigated by these waters. Already, a disproportionately large number of waterborne diseases have been reported in this area, especially among children [BAMAS 2005b].

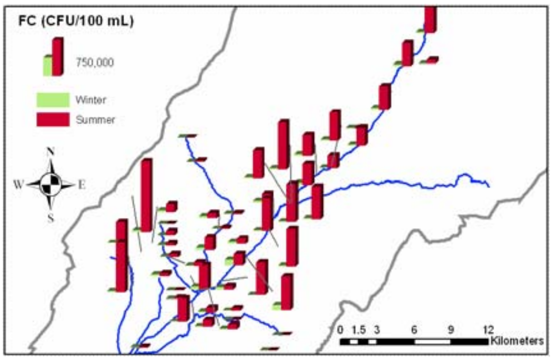

Figure 2. FC Measurements in the ULB (2005)

3. WATER QUALITY CONTROL IN THE ULB

To mitigate the debilitating state of water quality in the ULB, the Council for Development and Reconstruction (CDR), the leading planning agency in Lebanon, has developed and secured funds for an environmental master plan for the basin [CDR 2005]. The plan calls for the construction of 7 secondary wastewater treatment plants (WWTPs), with a total capacity of 118,530 m^3/day, and wastewater drainage networks to serve the majority of towns in the basin (Figure 3). Despite the relatively large scale of the $94 million-proposed development, whereby 75 towns with a total population of 445,940 are served, the plan neglects to provide coverage to over 65 towns with a total population of 63,000 (Figure 3).

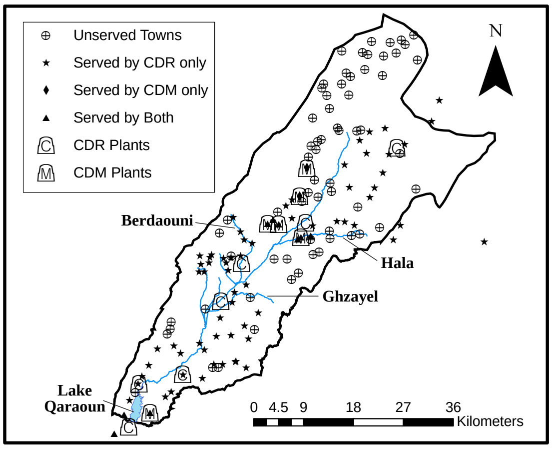

Figure 3. Coverage of the CDR and CDM Plans

Another water quality initiative is led by the USAID which retained the services of Camp Dresser & McKee (CDM) to develop a small community based wastewater treatment plan, where smaller capacity WWTPs are designed to serve one town or a cluster of closely located towns. At an estimated cost of $8,870 Million, the CDM plan involves the construction of 6 secondary treatment WWTPs with a total capacity of 14,840 m^3/s to serve 11 towns with a total population of 51,550. Although few of the towns excluded by the CDR plan are considered in the CDM plan, the two plans overlap indicating a lack of cooperation between the two agencies.

Both plans are formulated based on the general objective of reducing pollutant and nutrient loadings to limits set by the Ministry of Environment without assessing the overall impact of these plans on water quality in the river. Considering the significance of improving water quality in the basin and the substantial financial obligations required for adopting mitigation measures, it is imperative that alternative policy options are thoroughly assessed and selected based on the state-of-the-art and proven water quality management and decision support tools.

To meet this objective the authors have developed a decision support system (DSS), to address the complex water quality issues in the ULB, utilizing the Water Evaluation and Planning (WEAP) model.

4. THE WEAP MODEL

Developed by the Stockholm Environmental Institute (SEI) the WEAP model provides a GIS based virtual environment to graphically represent water demand sources, natural and man-made water resources supply and treatment systems including towns, irrigated areas, river systems, water and wastewater treatment plants, hydroelectric plants, etc. (Sieber et al 2005). The WEAP integrated approach emphasizes the importance of collective consideration of the main aspects of water resources planning, namely water supply and demand management, environmental impact and mitigation and financial analysis. As a planning tool, WEAP provides a flexible scenario-based approach to represent current and future conditions under different development schemes. Scenarios can be evaluated and assessed based on several criteria representing water supply conditions, water demand, environmental impact and financial cost and benefits. Input and output information can be presented in several charting options and tabular formats.

5. METHODOLOGY

The study consisted of three main tasks:

1. Development of the DSS simulation environment through setting up WEAP global parameters and creating objects to represent the ULB river system, towns, WWTPs, return flows from towns to rivers and/or WWTPs.

2. Setting up the DSS scenarios to capture current and baseline conditions and represent alternate water quality management schemes.

3. Run and analysis of scenarios’ results to assess the merits of mitigation schemes against given environmental performance indicators.

These tasks are presented and discussed in the following sections.

6. SETTING UP THE DSS SIMULATION ENVIRONMENT

The DSS simulation environment was set up to virtually capture as objects the following elements that significantly contribute to the state of water quality in the ULB (Figure 4):

- Towns which are represented as water demand centers where supplied water is partially consumed and returned to the environment with degraded quality characteristics. Towns are described in terms of attributes representing population, consumption and wastewater pollution loads per capita, water supply source and wastewater return destination and access to sewage facility.

- WWTPs, where wastewater is treated and released with improved quality characteristics. WWTPs are represented in terms of design specifications of total capacity, removal rates of pollutants and losses, and financial analysis information including capital and maintenance costs.

- River system which is made up of headwaters, reaches, confluence and wastewater return nodes. Reaches are represented as directional vector elements with water flowing in downstream direction. Headwater flows are entered as time series dictated by selected scenarios. Pollution loadings and water quality are tracked in the river system via a mixing and decay model.

- Return flows capture releases from demand centers or WWTP to the river system.

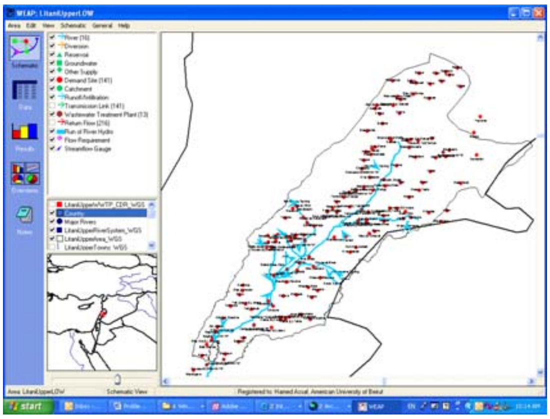

Figure 4. The ULB DSS simulation environment

All the 141 towns in the ULB, the CDR and CDM planned WWTPS, and the 8 rivers making up the Upper Litani river system, are captured in the DSS simulation environment as shown in Figure 4. Wastewater return flows are not shown in the figure to avoid obscuring other elements.

7. SETTING UP WATER QUALITY MANAGEMENT SCENARIOS

In the current study, three scenarios were setup and analyzed. One, referred to as the reference scenario, represents the business-as-usual conditions, where no water quality measures are introduced. Another considers the adoption of the CDR and the third represents the CDM plan. Scenarios are created and managed as a hierarchy, with all scenarios stemming from the parent reference scenario. Scenarios are described in terms of deviations from the reference scenario. All scenarios share the same time frame, which could be one year to several decades depending on the planning horizon.

Although elements are activated by given scenarios, they are all made visible in the DSS simulation environment regardless of when they get activated. For example, Figure 5 depicts a close-up of the lower third of the simulation environment, which shows the Litani River, one of the CDR WWTPs, several towns and their corresponding current and potential wastewater return flows. Perforated lines represent wastewater return flows under the reference scenario, where wastewater is released untreated into the river. Under the CDR plan, wastewaters are sent first to the WWTP where they are treated and then released into the river.

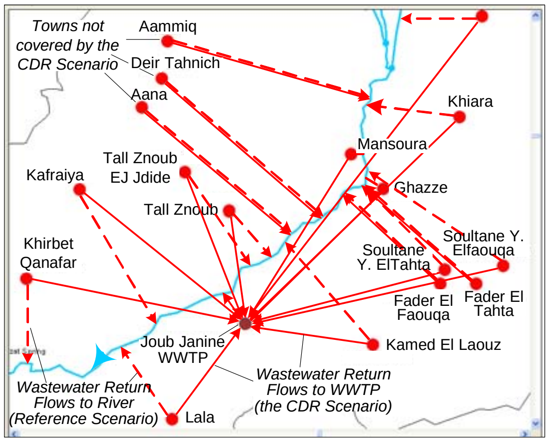

Figure 5. A snapshot of the ULB DSS simulation environment.

8. REPRESENTING HYDROLOGICAL VARIABILITY

River water quality in the ULB is highly influenced by variabilities in yearly and seasonal river runoff. Impact of sewage releases could be greatly attenuated by higher flows. However, under low runoffs, sewage pollutant loading of the same magnitude could render water hazardous for most uses. To represent the impact of river flow variability, the three selected scenarios are run against three hydrological records representing low, average and high river flows.

Examining the available record on inflows to Lake Qaraoun from 1962-present, three water years were selected. The year Sept 1999-Aug 2000 has the lowest total inflow on record. The year Sept 2002–Aug 2003 is the second highest on record, but was selected to represent high flow conditions since flow records for the Litani's tributaries are not available for the highest flow year. Average flow conditions are represented by the year Sep

2003-Aug 2004. The monthly discharges of the three selected years are shown in Figure 6.

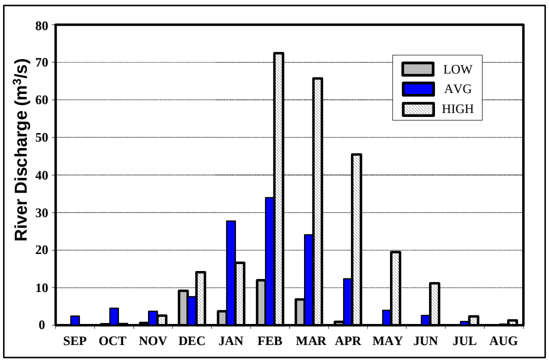

Figure 6. Monthly discharges for the selected water years.

Three sets of 20-year monthly discharge time series for the Litani River and its tributaries were assembled. Each series is composed of monthly discharges corresponding to one of the low, average, and high water years repeated over for a 20 year period. The reference, CDR and CDM scenarios were then simulated against each set of the river discharge time series.

9. DSS SIMULATION RUNS AND ANALYSIS RESULTS

The simulation of the three scenarios against the selected water years has generated a very large set of outputs describing, disaggregatetly, all attributes of elements and variables in the simulation environment. For the purpose of this paper, the three scenarios are assessed only in terms of the Biochemical Oxygen Demand (BOD). Technically defined as the amount of oxygen required by aerobic microorganisms to decompose organic matter in a sample of water and measured in milligrams of oxygen per liter of water (mg/L), the BOD is a widely used environmental performance indicator (Chapman 1996).

A sample of calculated BOD levels are presented to characterize the domestic wastewater induced pollution of surface water in the ULB from five key perspectives of seasonal variability, spatial extent, future trends, hydrological conditions, and alternative water quality management options. Figures 7, 8, and 9 show sets of monthly BOD plots at three locations on the Litani River, listed in upstream to downstream order with river kilometers from the Litani headwater as follows (Figure 1): below the confluence with Hala River (24.2 kms), below the confluence with the Ghzayel River (42.1 kms), and at the entrance to Qaraoun Lake (64.5 kms), respectively. For each location, a set of 9 plots are presented, that depict calculated monthly BOD levels for the reference and the CDR and CDM scenarios, for the three river discharge conditions, and for the present year (2005), year 10 (2015), and year 20 (2025) projected conditions. The plots are organized in a tabular format, where rows represent changes over time and columns show variations due to river discharge conditions.

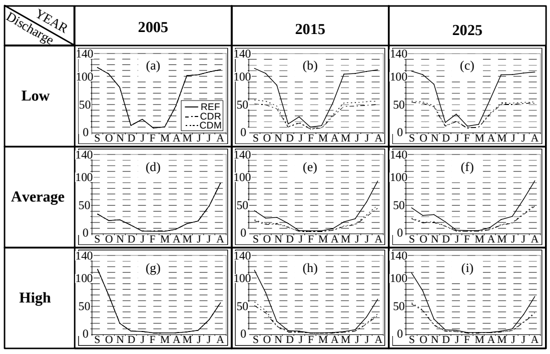

Figure 7. Monthly BOD (mg/l) in the Litani R. below Hala R.

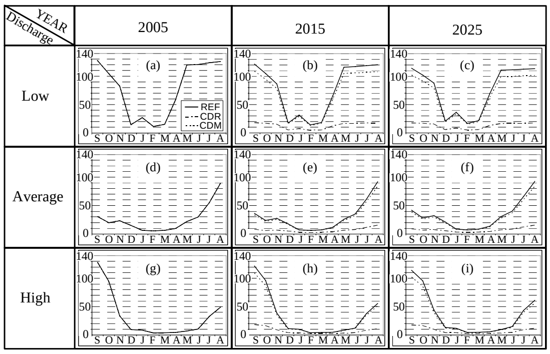

Figure 8. Monthly BOD (mg/l) in the Litani R. below the Ghzayel R.

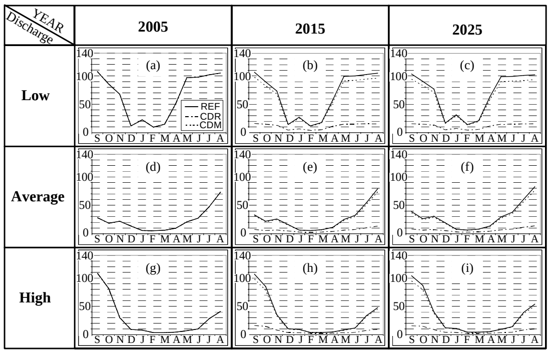

Figure 9. Monthly BOD (mg/l) in the Litani R. above Lake Qaraoun.

A general overview of Figures 7, 8, and 9 shows a consistent seasonal variation in BOD levels strongly associated with river discharges (Figure 6), with BOD levels reaching a high 140 mg/L during the driest months of the year (July to September), and values lower than 5 mg/L during heavy runoff months (February and March), especially during the wettest year. In comparison unpolluted waters generally have BOD values lower than 2 mg/L, wastewater polluted waters have values higher than 10 mg/L and BOD levels reaching 600 mg/g for raw sewage (Chapman 1996). Given that the calculated BOD levels represent monthly means, daily or hourly values are expected to vary more considerably as a result of higher variability in daily or hourly river discharges and pollutant loadings.

Plots (b),(c), (e), (f), (h) and (i) of Figures 7, 8, and 9 show that the implementation of the CDR master plan would greatly reduce the impact of domestic wastewater on water quality, especially in the middle and lower reaches of the river. However, BOD levels are expected to stay excessive in the subbasin above the confluence with Hala River during the drier months of the year. These observations are attributed to the disproportionately large number of towns excluded from the plan (see Figure 3), and the typical lower water yield of this sector of the ULB in comparison to the middle and lower sectors.

The CDM plan is expectedly less effective overall than the CDR plan due to its limited scope and coverage. However, the effect of the CDM plan is quite similar to that of the CDR plan, in the upper region above the confluence with the Hala River since, five of its six proposed WWTPs are located in this area (see Figure 3).

10. SUMMARY AND CONCLUSIONS

The current practice of discharging untreated sewage into the Upper Litani river system is causing wide-scale pollution that escalates to alarmingly hazardous levels during drier times, which last for a longer part of the year, and possibly for several years in a row during drought spells. This situation is particularly worrisome considering that this unabated contamination of scarce and valuable fresh water resources has made them unusable, especially during drier and high demand times. “Quality is compromising supply” as articulated by Cadham etal (2005), in reference to the environmental degradation of the water quality in the Akkar watershed in Lebanon and Syria, is equally applicable to the similarly grave conditions in the ULB.

A GIS-based DSS has been developed to help decision makers and other stakeholders assess alternative policy options in mitigating water pollution in the ULB. The DSS is developed based on the WEAP model, which provides a virtual integrated simulation environment to represent elements and variables that shape water quality conditions in the basin.

The DSS was used to project and assess water quality conditions in the ULB under three scenarios representing continuation of present practice, an environmental master plan by the CDR, and a small scope plan sponsored by the USAID. The results show that the CDR plan is effective overall in improving water quality, except in the less served upper region of the basin and during dry flow conditions. The CDM has much less overall impact due to its limited scope, although it has similar impact in adequately served areas.

11. ACKNOWLEDGEMENT

The authors thank the Litani River Authority for their valuable cooperation and provision of information that was necessary for the success of this study.

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