MULTI-OBJECTIVE OPTIMIZATION MODEL FOR THE EXAMINATION OF WATER REUSE POTENTIAL IN LEBANON

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PROBLEM STATEMENT: Water stresses in the eastern Mediterranean region are causing severe impacts on both human and natural systems and raising tensions between and within nations. The Lebanese Ministry of Environment is now actively seeking novel technologies, strategies, and/or management practices that will reduce water stresses in their nation. As no one entity has yet proposed a satisfactory solution to the region's approaching water crisis, there is an immediate and pressing need for research in this area. New water sources are not available. Desalination is, at present, prohibitively expensive. Demand management will, at best, reduce current stresses on water sources to an acceptable level, but it does not allow for the effect of population increases on domestic, agricultural and industrial water demand. Lebanon currently recycles less than 2% of its wastewater, thereby failing to utilize one of its most ready and reliable potential sources of water supply. This study will fill the existing research gap by designing and implementing a novel method of water system analysis different from all previous, more singular, approaches. The objective of this study is to determine the degree to which advanced wastewater treatment technology can be utilized for water reuse to help meet the needs of humans and the environment in the semi-arid countries of this region. By employing the principles of integrated water resources management, I will develop a multiple objective optimization model (MOOM) to determine the quantity, quality, and geographic location of water reuse technology that would best alleviate water stress in Lebanon.

BACKGROUND: The 2001 Lebanon State of the Environment Report explained that despite seemingly abundant water resources, "Lebanon is poised to experience a water deficit within the next 10-15 years, unless sound and radical water management policies are developed and implemented. Water stress in neighboring countries including Syria, Jordan, Israel and Palestine is a harsh reminder that Lebanon must rethink its water strategy in the shortest delay possible, protect water resources and use them more judiciously" (LEDO, 2001). This proposed research will conduct an integrated political, socio-economic and biophysical analysis of water issues in Lebanon to propose solutions to present and future stresses. Lebanon is an excellent case study to examine regional water issues because of its fairly reliable store of available fresh water, the recent stability of its socio-political conditions, and its expressed intention to improve its water infrastructure.

If unchecked, Lebanon's water supply problems will worsen in the near future. Lebanon's population was about 4.3 million in 2001 with an annual increase of approximately 1.65 percent. As of 1997, Lebanon possessed 766-1,287 m^3 renewable water resources per capita. Those numbers are projected to decrease to 336-979 m^3/capita by 2015 and 262-809 m^3/capita by 2025. This means that it will be unable to meet its local demand by 2025, to say nothing of the long-held view that Lebanon is [relatively] water rich and that it can and should share its excess water resources with its neighbors. In 1994, total water demand in Lebanon was 1,285 million m^3 per year, of which 74%was used by agriculture, 16% for domestic consumption, and 10% by industry (LEDO 2001). Water demand is projected to escalate to 3069 million m^3 per year by 2015 with 49% going to irrigation, 29% to domestic consumption, and 22% to industry. To make matters worse, water resources in Lebanon are believed to be particularly vulnerable to climate change due to Global Warming (flooding and desertification), since it is located at the border of desert regions and more than 60% of its economic activity lies in a narrow coastal plain along the Mediterranean Sea (Bou-Zeid and El-Fadel, 2002).

Lebanon generates approximately 249 million m^3 per year (65,800 MGY) of wastewater, up from 165 million m^3 per year (43,600 MGY) in 1991. In 1991, the quantity of treated wastewater was roughly estimated at 4 million m^3 per year (1,000 MGY) and the quantity reused at 2 million m^3 per year (530 MGY), less than 2 percent generated (LEDO 2001). The untreated wastewater infiltrates from cesspools to groundwater or flows directly from sewer pipes to the natural watercourses. About 37 percent of nearly half-million buildings in Lebanon were connected to sewers in 1997. Significant improvements have made to the sewer network, though little has been achieved in terms of wastewater treatment. Clearly, wastewater in Lebanon represents both an immediate public health concern and a vast untapped resource.

METHODS: Integrated water resources management is a remarkably complex field of study. No single measure exists by which decisions can be made regarding water use within a given watershed. Water use decisions based primarily on achieving the most favorable economic ends often do so at the detriment of society and the environment. Environmentally-motivated policies rarely achieve their desired ends because they are shown to be economically unfavorable. Many potential solutions combining environmental and economic benefits are rejected a priori based on some significant way in which the solution deviates from cultural norms. To date, no model has succeeded in quantitatively comparing the alternatives to traditional water management in Lebanon.

To meet this need, I will first divide the country into hydrologic zones. Each zone will be characterized by a water and pollution balance equation that considers demand management (conservation), desalination, new water sources, recycling, and reuse for their potential contribution to meet Lebanon's human and natural systems needs for water. Because of the numerous considerations required by the water reuse investigation, I will develop a MOOM to determine the most favorable relationship between competing influences. At the simplest level, the model will be divided into the following component parameters: 1) economic, 2) technological, 3) public health, 4) environmental, and 5) social/political. Indicators will be assigned to each component. I will then subject each of the sets of parameters to constraints based upon my best interpretation of both the physical realities and the more subjective social and political preferences. The general form of the objective function will then maximize the weighted sum of net benefits from each of the five objectives.

For instance, by establishing public health constraints, I will answer the question, "What levels of technology must be employed to adequately protect human health?" As part of a larger model, the answer will be derived from a series of equations which together quantify the upper and lower bounds of all public health requirements. For example, one set of equations will represent bounds on bacteria levels in surface waters, while another set of equations will represent bounds on heavy metals in groundwater aquifers. Economic constraints will utilize "willingness to pay" criteria as well as establishing bounds on maximum possible expenditures. Technological constraints will bound the model by the physical and chemical limitations of available treatment technology. Environmental constraints will quantify such factors as minimum acceptable flows in rivers and storage in lakes, as well as maximum acceptable contaminant loads to sensitive receiving waters. Social/political constraints will quantify the receptiveness of the community to varying degrees of water reuse and compare it to other available technologies. They will also consider the susceptibility of various technologies and management schemes to political obstacles and social instability in the region. Scenario analysis will be used to consider issues associated with uncertain future populations and water demands, climate change, and advances in technology.

ANTICIPATED RESULTS AND BENEFITS: The model output will provide valuable insight into the quantity, quality, and most strategic geographic location for water reuse technology, in combination with other sources, that would best alleviate water stress in Lebanon. Once the model successfully suggests improvements for Lebanese water management, it would then serve as a prototype to other similarly water-stressed nations in the eastern Mediterranean region and elsewhere.

LONG-TERM GOALS: I expect to dedicate the bulk of my engineering career to international water development, both engineering and political, especially in North Africa and the Middle East. This study has been designed based upon its relevance to my broader professional ambitions.

As an MS/Ph.D. student at Tufts, I will enroll in the engineering, economics, development and public health courses relevant to this study. The first year of research will be largely consumed with data collection, strategy drafting, relationship development with collaborators, and coursework. Years two and three will involve significant periods of travel to Lebanon, data collection, coursework and development of the MOOM for one region of Lebanon. During years four and five, the model will be calibrated, tested, expanded to include the entire nation, and the results examined in the preparation for a Ph.D. dissertation. I have received commitments for collaboration from staff in various departments at Tufts University including the Civil and Environmental Engineering Department, the Water Sustainability, Health and Ecological Diversity (WaterSHED) Center, the Fares Center for Eastern Mediterranean Studies, and the Fletcher School of Law and Diplomacy. Faculty in the Civil Engineering Department at the American University of Beirut (AUB) in Lebanon will provide information and expertise with respect to water reuse issues unique to Lebanon. Additionally, Dr. James Crook, a distinguished and highly regarded water reuse professional and author of *EPA's Guidelines for Water Reuse* has offered to support me in the analysis.

Frequent travel to and from Lebanon will be an essential element of the success of this research. Money awarded by the Tufts Institute for the Environment would be applied to finance the first (and most crucial) trip to Lebanon during the summer of 2004. Professors El-Fadel, Ayoub and Basha at the AUB are ready to receive me this summer. The total travel and equipment expenses are expected to amount to approximately $6,000.

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