USE OF SYSTEM DYNAMICS FOR MANAGING WATER IN JORDAN

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Abstract
Management of scarce water in Jordan requires development and operation of expensive water facilities and making hard policy decisions. System Dynamics is used to represent the structure of the water sector in Jordan and to test potential policy decisions and water development scenarios. This paper discusses the potential use of System Dynamics simulation models to serve as tools to aid water managers and policy makers in making management decisions and long-range water strategies.

Key words: water management, System Dynamics, long-term water strategies and policy analysis.

Approach and Design Philosophy
Jordan's Water System Dynamics Model was built in an attempt to represent the complex ***structure*** of the water sector in Jordan. The model was designed with the intent of providing a water management tool that would give water managers, planners, policy and decision makers flexibility in assembling and testing ***long-term water*** strategies for the country. A strategy may include structural measures to increase the supply capacity, as well as managerial options to manage water supply and demand and to allocate water supply sources for use in municipal, industrial or irrigation purposes.

The simulation system is designed with the notion that there are severe limitations on the processing and computing abilities of human managers and decision makers *(1)*. Such a notion focuses attention on the flow of information in a complex water resources management system, and it focuses on the use of such information in the decision making process. It also focuses attention on the role that simulation can play in gaining insights into current and future water management policies in the country.

Three types of information were used in the simulation system: mental, written and numeric. The *mental information* relied on the mental data base of the authors and their colleagues and it seemed to reliably capture the structure and policies governing management of the water sector in Jordan. *Written data* on the Middle East and Jordan's water problem abound. Several articles, television programs, and conferences have tried to describe its current and future implications. *Numerical data* used in building the simulation system were collected and reviewed from several sources: consultants' reports, unpublished data from the water management entities and the Dept. of Statistics in Jordan.

Structure of Jordan's Water Sector System Dynamics Model
The simulation system was formulated using STELLA II® model building environment with two main layers for easy interaction with the model users: the High-Level Mapping & Input/ Output layer, and the Model Construction layer. The High-Level Mapping layer is used as a decision, or policy analysis center, while the construction layer is used to construct the details of the model.

The simulation system consists of five major sectors as illustrated in Figure 1. The *water financial sector* includes details of the capital and operation and maintenance financial analysis. It is further divided into two subsectors, the first dealing with capital cost recovery and the second with the debt and tariff setting mechanisms employed in the analysis. The *water supply and demand management sector* includes the model representation of population, per capita water demand and the supply and demand management options. *The capacity expansion sector* lists the starting dates, capital costs and water supplies from the proposed municipal and industrial water supply projects. It also includes the projects needed should the water management strategy call for a reallocation policy to be activated. The *water resources and supply sector* lists the water resources diverted for municipal, irrigation and industrial uses. It also includes the surface and groundwater resources of the country, and lists their past uses and future potentials. This sector links the Jordan Valley model and uses its output, particularly for municipal water supply. Finally, the *Jordan Valley irrigation system operation sector* includes the output from an auxiliary simulation model that operates the Valley's irrigation infrastructure. It also includes the potential future development of dams, diversion structures and pump storage facilities for both irrigation and municipal and industrial purposes.

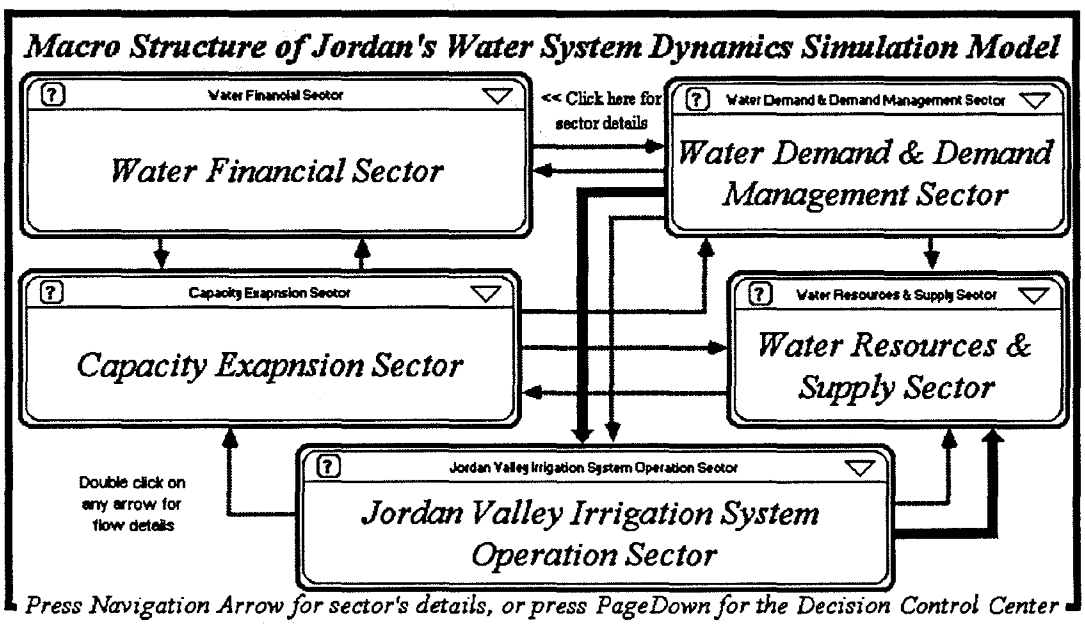

Figure 1: Macro Structure of the Simulation System

Each sector represents water management from the point of view of the entity responsible for that particular sector within the organizational structure of Jordan's water management institutions. The simulation system provides several outputs that describe the structural behavior of the water sector in Jordan. A collection of important outputs were used to formulate "Performance Indicators" that serve to measure the achievement of the objectives of the water sector.

The System Dynamics approach used in the analysis enables the analysis of the water management system in terms of its processes, information linkages and feedback mechanisms. The approach facilitates quantitative simulation modelling and analysis for the design and control of a structure for the water management system. The interactive computer simulation environment and the "Decision Control Center", that contains the strategy's design decision variables were designed with one goal in mind: to help achieve a consensus between parties involved in setting policies and making decisions for the water sector.

Feedback Mechanisms

The concept of feedback information loops *(2, 3)* was employed most heavily in the *Water Financial Sector* to investigate the behavoir of the water tariff required to reach a desirable debt level. For example, tariff setting mechanisms depend heavily on the feedback structure which is influenced by the accumulations in capital cost recovery instalments and debt, and by the available installed capacity required to meet water demand. As water demand increases, the forecasted capacity required rises and water planners typically initiate plans to meet the increasing demand. However, planning and construction delays prevent the installed capacity from increasing in time. Figure 2 shows that the construction and demand loops are interconnected to act over time to change the demand as well as the installed capacity. Once the new installed capacity reaches the commissioning stage, changes in water tariffs become needed to reflect the cost of water with the new facilities. A delay in approval of new tariffs takes place as this approval has to pass through the regulatory agencies and the Cabinet of Ministers. Once it is approved, the actual price of water increases leading, in turn, to a decline in water demand.

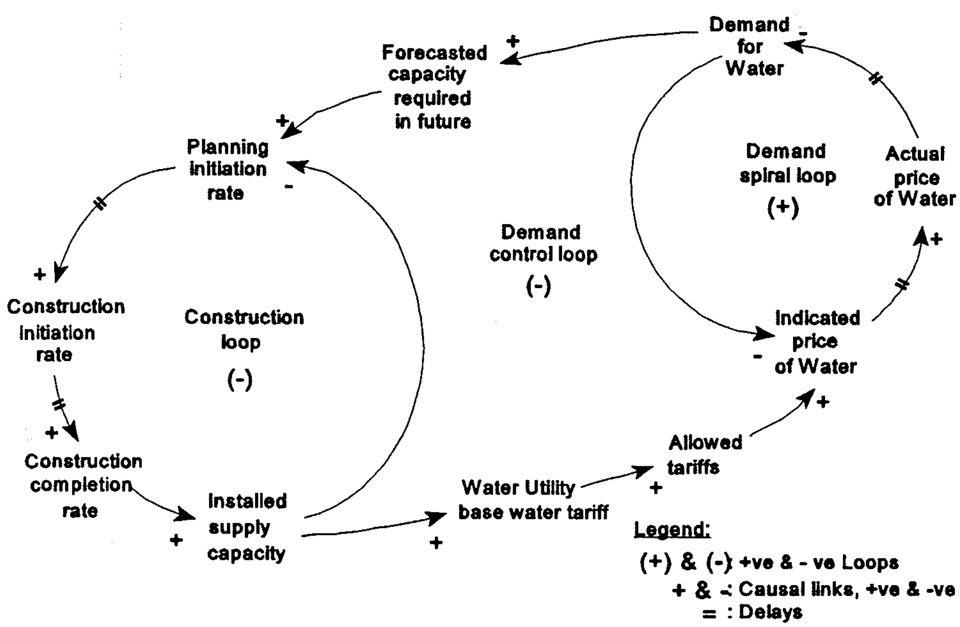

Figure 2: Feedback loops in the water sector *(After Ford, 1983)*

As one works his way through these two loops, they most likely tend to eliminate the original change in demand. This characteristic of negative feedback loops that act to control system behavior, has been named the demand control loop *(4)*. Many other feedback loops that determine the behavior of the water sector in Jordan were built into the model.

Testing Proposed Water Management Strategies

The simulation system was used to test four long-term water strategies: current water strategy, current and water desalination strategy, current and water import strategy, and water reallocation strategy. The strategies include a set of capital and non-capital projects that enhance water supply and demand management. Water supply projects includes development of the remaining supplies within Jordan, as well as water imports from neigboring countries (Syria and Iraq). They also include the option of desalinating Sea water at the Gulf of Aqaba at the Red Sea. Non-capital projects include supply and demand management options, programs to enhance revenue collection, leakage reduction and public awareness and water conservation programs.

One of the more interesting results of the simulations (Figure 3) is that the water import strategy is the most financially feasible strategy for the country. This, however, is counter intuitive, since the most widely held belief, even among the international financing agencies *(5)*, is that the water reallocation strategy is the most appropriate for the country. However, political preferences of the policy maker could dictate the use of a mix of the three above mentioned strategies.

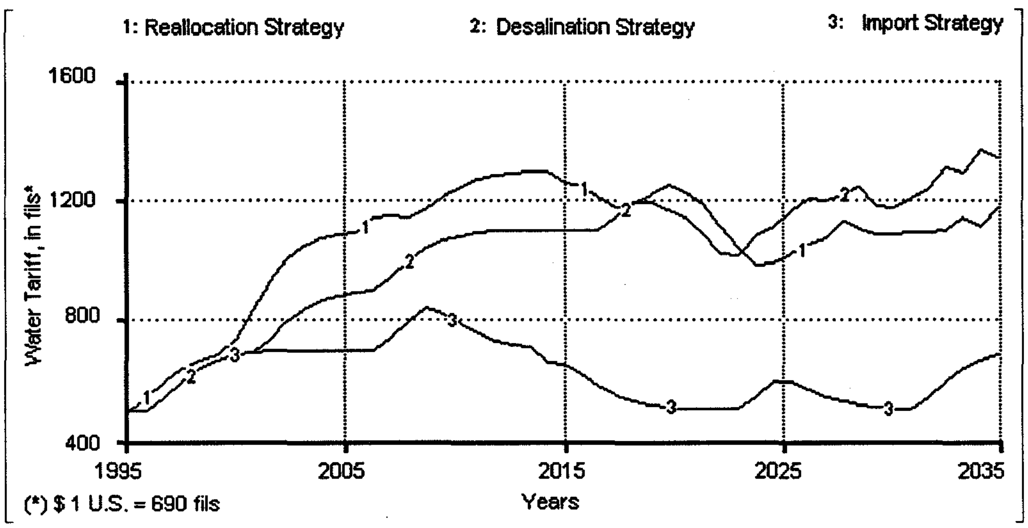

Figure 3: Tariff Behavoir for the Three Water Management Strategies

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