OBJECT-ORIENTED MODELING FRAMEWORK FOR WATER RESOURCES POLICY ANALYSIS

by

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ABSTRACT

Water resources management is becoming more and more important. The need for fresh water is increasing as the world population expands. Most human activities require water. Water is used for domestic consumption, agricultural supply, industrial supply, electric power generation, navigation, etc. The competition for available water resources is very strong. The need for wise planning and management is emerging. Water resources planning and management decisions are based on several issues. The economic, political, social, and environmental consequences of any decision must be clearly identified before implementation in order to minimize harmful impacts that might not be reversible.

Mathematical models are the tools used to support decision making. They allow the simulation of system performance and the evaluation of the effects of management policies. The benefits of using mathematical models are numerous. They include the ability to test a wide range of policy choices, and the ability to give protection from unfavorable situations that might be unforeseen at the present time. The current development trend in the field of computer programming languages aims at facilitating the modeling process and creating programs which are easy-to-understand and use. The object-oriented programming languages are among the latest outcomes of this trend. Object-oriented programming introduces a new way of thinking that envisions a system as interacting components with distinctive identities. The main advantages of using object-oriented programming are the transparency, flexibility, and reusability of programs developed using this approach.

The objective of this research is to develop a new framework for water resources policy analysis. The new framework utilizes object-oriented programming, as a state-of-the-art methodology. The research addresses the usefulness and advantages of using an object-oriented approach over traditional programming. The framework has a feedback component which allows the system to make necessary modifications to the tested policy along the simulation process. The framework developed in this research is tested in the field of water resources. An interpretation of each of the framework stages is introduced using the most common cases. The framework is then implemented to produce a general model using STELLA II as an object-oriented programming environment. The general model is used for water resources policy modeling. The analysis of Egypt's water resources policy has been selected as a case study. More emphasis was given to agriculture as the main water demand sector, and the River Nile as the main water resource.

The process of developing a policy analysis model using the object-oriented approach has proven to be efficient. Using the developed framework allows complex components of water resources system structure and functional relationships among the system components to be clearly identified and to be easily implemented. Adaptation of the general model to accommodate the Egyptian water resources policy analysis was an easy and straightforward task.

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At this time, I would like to express my gratitude for the people who were in support for me throughout my Master's degree studies. Their continuos understanding and support made it possible for me to reach this point in my career. While it is not possible to mention everyone, I would like to specifically thank selected people.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

Water problems are among the most important and persistent problems for many developing or developed countries. The increasing need for water to be used for a variety of purposes and activities is straining the existing resources and causing many development opportunities to be missed. Water is needed for human consumption, agriculture and live stock as a means of food, in industry for washing and cooling purposes, for power generation either by water falls or for turbine cooling in thermal and nuclear power stations, and for navigation as a cheap means of transportation. In addition, environmental awareness and ecosystem conservation are compounding the problem. Sustainable development criteria require abandoning some of the previous misuse practices of water resources in order that future generations will have enough and clean water to meet their needs.

Developing a policy for water resources management is not easy. Many aspects, such as economic returns, social welfare, environmental hazards, and political constraints should be taken into consideration. A good water policy must fulfill, to a satisfactory level, all of these criteria. The evaluation process of a policy requires thorough knowledge of all the consequences that might result due to its implementation. The use of simulation models allows water policy planners and decision-makers to identify the effects of their policies prior to implementing them in the real world. A policy analysis model is a tool in the hands of decision maker to help them create a policy that is convenient to water users, and appropriate in terms of ecosystem conservation.

Currently, most of the decision makers are reluctant to use computer models. One of the main reasons is that most of the models are complicated to such a degree that the decision maker cannot follow the logic of the model. Another reason is that most of the models are tailored for specific cases making it almost impossible to include components that are not in the model in the first place, or even to modify one of the existing components.

1.2 RESEARCH OBJECTIVE

The objective of this research is to develop a new framework for water resources policy modeling. The new framework introduces and utilizes an object-oriented modeling approach, as a state-of-the-art methodology, and applies it to the modeling of water resources policy. The research addresses the usefulness and advantages of using object-oriented modeling over traditional modeling approaches. Among the recognized advantages of object-oriented methodologies are the transparency, flexibility, and reusability of the models. Application of an object-oriented modeling framework to water resources system management can make decision makers less reluctant to use policy analysis models, can give them more confidence in the model results, and can allow them to manipulate the system components with much less programming knowledge.

1.3 SCOPE

The scope of the research revolves around the use of object-oriented methodologies to create a modeling framework that is capable of assisting decision-makers in identifying an efficient water resources policy. An eight-stage framework is developed to translate the basics of object-oriented modeling into a water resources system domain. The suggested framework is not limited to a specific case. Rather, it can be used to model any water resources system under a variety of conditions. Also, the framework is not limited to a particular object-oriented programming language and can be used with most languages as long as they support the object-oriented modeling approach.

The work done in this thesis begins in Chapter 2 with a review of the previous modeling activities and the different modeling techniques. Chapter 3 gives a review of the object-oriented modeling approach, terminology, and programming languages. The description of the object-oriented modeling framework starts in Chapter 4 by defining its stages, and explaining in detail the procedure to be followed to implement each stage. Chapter 5 introduces a practical implementation of the framework to produce a general model based on the framework using one of the object-oriented modeling environments, STELLA II. The model created is considered as a general base for application to any water resources system. In Chapter 6, the general model is modified to be used to study the water resources system in Egypt. Chapter 7 summarizes and concludes the work done, and Chapter 8 gives some suggestions for possible future development.

CHAPTER 2

LITERATURE REVIEW

2.1 SYSTEM APPROACH TO WATER RESOURCES

2.1.1 WATER RESOURCES PLANNING

Water resources planning and management has gained a lot of attention all over the world. This increasing attention has arisen due to the rapidly increasing demand for water within the limited, and uncertain, supply of water. Water demands are increasing due to many factors such as population increase, industrial development, and urbanization. Moreover, the available resources are suffering from the declining water quality that may limit their use.

Water resources planning aims at making the most effective use of available water resources to meet all the foreseeable short- and long-term needs of the nation (Kuiper, 1965). The most effective use of water resources requires the maximization of the benefits, not only economic but social and environmental as well. This definition also implies that water resources planners should consider both the current and future needs as the next generations also have the right to enjoy sufficient clean water.

One of the main objectives of water resources development is considered to be the maximization of regional welfare. This primary objective can be interpreted in different ways such as (Buras, 1972):

1. the attainment of economic efficiency
2. the generation of distributed income in the region.
3. the stimulation of full employment.
4. the promotion and support of economic growth.
5. the achievement of certain intangible and/or non-quantifiable objectives.

In order to achieve the above mentioned objectives simultaneously, an integrated way of thinking must be employed. Water resources systems should be studied as one system with interacting subsystems rather than as separate components of resources and demands.

The pressure on water resources is continuing to increase. The only solution available at hand is to introduce better means of planning and management for the system and to utilize all technology in discovering the most effective strategy to combat the water shortage problem now and in the future.

2.1.2 SYSTEMS APPROACH

Water resources systems are usually complex in nature. The involvement of several interest groups in water resources planning and decision making makes it harder to reach what can be called "the optimal plan". In order to obtain a clear understanding of any water resources system, a well-defined procedure must be followed. System thinking is the way to see the whole picture of the system rather than concentrating on details.

System analysis, also known as operation research, can help define and evaluate, in a rather detailed manner, numerous alternatives that represent variable possible compromises among conflicting groups, values, and management objectives (Loucks et al., 1981).

First we need to identify an acceptable definition of a system. One definition says that a system is "a regularly interacting or interdependent group of items forming a unified whole". Another definition says that a system is "an organized set of doctrines, ideas, or principles usually intended to explain the arrangement or working of a systematic whole" (Deutsch, 1969). Finally, Chorafas, 1965, defines the system as "a group of interdependent elements acting together to accomplish a predetermined purpose". He also defines system analysis as "an attempt to define the most feasible, suitable, and acceptable means for accomplishing a given purpose". System analysis seeks the determination of the best course of action, or decision, for a problem under the restriction of limited resources (Taha, 1995). This term quite often is associated with mathematical techniques used to model and analyze decision problems.

Systems can be either static or dynamic. Static systems are those whose current outputs depend only on the current inputs. Dynamic systems are those whose current output depends on both current and past inputs (Auslander et al., 1974). This definition might be confused with an active system. A static system can be active, changing with time, if the inputs change with time. A dynamic system can be active if it is not in a state of static equilibrium.

Two major types of systems can be identified. The first is an open system. This type depends on a set of inputs in order to produce a set of outputs in a linear and irreversible manner. This means the outputs produced in a previous time frame do not have any effect on the current system inputs or on future system performance. The second type is a feedback system. For this type of system a measurement of the system output is used to regulate the system input in such a manner that the output stays close to some desired value (Auslander et al., 1974). Other references suggest two types of feedback systems; negative and positive. The negative feedback system is a system with a desired value for the outputs that the system is aiming to reach. The positive feedback system is defined as a growth system where the actions build results that generate greater action and so on.

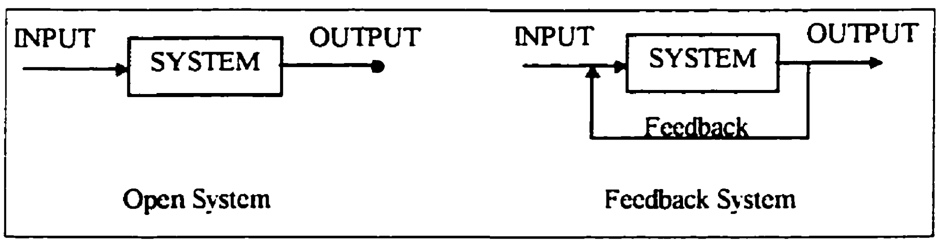


Figure 1: Types of Systems

2.1.3 Systems Modeling

The modeling of complex systems can take many forms. Among these forms are physical models and mathematical models. Physical models simulate the system to be examined on a smaller or larger scale. These models were the most common type before the invention of high speed computers. In the water resources field, physical models can be used efficiently for smaller, specific problems which can be found in river engineering and hydraulic structures design. Although the physical model can provide good results and a visual representation of the system's behavior, the allocated cost for building a physical model is relatively high due to space requirements, and construction, operation, and maintenance costs. Moreover, physical models are neither flexible nor reusable for cases other than those for which they are designed. Modeling complex systems on the policy level using physical models is not appropriate.

2.1.3.1 Mathematical Models

Mathematical models simulate the system's behavior using the relationships between the system components and the way they interact with each other. High speed computers allow modelers to deal with large complex water resources systems such as natural watersheds and river basins. The simplicity of the mathematical formulation facilitates creating very detailed models capable of integrating different aspects of economy, environment, society, likelihood of success, associated risks of implementation, and political viability (Fahmy and Aboelata, 1995).

The success of a model depends on its clear purpose, data reliability, and an appropriate description of the system's dynamics. Unfortunately, lack of information and ineffective communication among modelers and users create many problems. The first problem is the lack of reliable data that gives the model its credibility and truthfulness. Consequently, planners are hesitant to use it unless they have complete confidence in its data. The second problem is the inability of modelers to understand the real needs of the users for whom the model is developed. The consequence of this problem is that the model produced is not satisfactory for the users and its use becomes limited.

In order to create a model that can be useful, Mohammadi et al. (1991) suggests the following eight guidelines:

1. general purpose models should be small to cover a limited range of local decisions, while models with well defined objectives can cover an entire river basin;
2. models output should be structured to provide the multi-level users with only the information they need;
3. during the modeling process, joint and continuous cooperation between modelers and potential users must be established;
4. data collection and documentation is a continuous process;
5. high level management support, funding, and effective communication are very important issues for the success of the modeling process;
6. the model must be open for evaluation and review;
7. marketing the model through government agencies and political users is very important. A good documentation can help in marketing; and
8. exchange of ideas in the field of water resources management must be encouraged.

Mathematical models can be further divided into two main categories: optimization and simulation models.

2.1.3.1.1 Optimization Models

Optimization models assume that the objective function and the constraints of the model can be expressed mathematically as functions of the decision variables (Taha, 1995). Results of optimization models always represent the optimal solution for the modeled problem. In some cases, the problem to be modeled can be very complicated so that its representation in an optimization model will not be complete. Developing an optimization model requires great attention to the nature of the problem and the interactions among all components of the system.

Many solution algorithms have been developed to solve optimization models depending on the nature of the objective function and the constraints. Optimization models are used widely in water resources problem solving. They can use a single objective such as maximization of hydropower generation or multiple economic, environmental, and social objectives.

Many techniques are available for formulating and solving an optimization problem. Linear programing (LP) has been one of the most widely used mathematical programing technique for optimization of water resources systems (Srinivasan, 1996). This technique requires the objective function as well as all constraints to be in a linear form. The advantages of this technique include the ability to identify a global optimum solution and the availability of ready-made software packages that help the planners concentrate on problem formulation. Some problems which have nonlinear objectives or constraints can be linearized using some approxmation methods such as piecewise linearization. The major uses of LP in the field of water resources management are reservoir planning and operation, water supply networks design and operation, hydropower generation, water quality modeling, and reservoir sizing as in Dorfman (1962) and Meier and Beightler (1967). Other examples of LP application in water resources systems can be found in Daellenbach and Read (1976), Takeuchi and Moreu (1974), Draper and Adamowski (1976), Grygier and Stedinger (1985), and Reznicek and Simonovic (1990) sited by Srinivasan (1996).

Another commonly used technique in solving water resources optimization problems is the dynamic programing. This technique is commonly used with multistage decision processes. The advantages of dynamic programing include the ability to include nonlinear relationships which characterize a large number of water resources systems, and the ability to handle problems with large numbers of variables by decomposing them into a series of subproblems to be solved recursively (Yeh, 1985). The drawback of dynamic programing in the water resources field is the inability to handle large scale water reources problems. The curse of dimensionality, as stated by Toebes et al. (1981), is a strong function of the number of state variables causing the number of possible combinations for the solution of a problem to increase exponentially so that it requires computers with much greater computational capabilities. Dynamic programing is popularly used in the field of reservoir operation for both short- and long-term planning and management. Some of the applications can be found in Allen and Bridgeman (1986), Kelman et al. (1990), Saad and Turgeon (1988), and Turgeon (1981) sited by Yeh (1985).

2.1.3.1.2 Simulation Models

Simulation is perhaps the most widely used method for evaluating alternatives in water resources systems. Mathematical simulation involves the construction of a working mathematical model presenting properties or relationships similar to the natural or technological system under study (Chorafas, 1965). The reason for its popularity lies in its mathematical simplicity and versatility. Although simulation models are easier to develop than optimization models, they can introduce more complexity in the problem description than optimization models. Simulation models break down the modeled system into basic or elemental modules that are linked to one another by well-defined functions. The process in simulation models starts at the input module and continues through the interactions among other modules ending with the output results. Unlike optimization models, simulation models do not give the optimal solution for the studied problem. Rather, they give the chance to analysts and planners to conduct a more thorough and detailed investigation of the system's behavior. Simulation models are considered an excellent means for evaluating the expected performance resulting from any design operating policy (Loucks et al., 1981).

In the water resources field, many simulation models have been developed for water resources planning, management, operation, and policy analysis. In the field of planning and management, a number of generic programs have been developed to simulate water resources systems such as HEC-3 and HEC-5. The HEC-3 model (Reservoir system analysis for conservation) and the HEC-5 model (simulation of flood and conservation system), developed by Hydraulic Engineering Center, US Army Corps of Engineers, are both used for the simulation of the response of the water resources systems designed to satisfy simultaneously a variety of water-based needs (Yeh, 1985). There have been many applications of these two models in many cases of multi-purpose water resources systems management. In water resources policy modeling, the WEAP model (Water Evaluation And Planning System) is a program for evaluating policies and developing sustainable resource plans (Raskin, 1996). IWRMSD (Integrated Water Resources Model for Egypt's Sustainable Development) was developed using an object-oriented approach to simulate the effects of future economic development policies on the water resources system, as well as the social, economic, and environmental effects. Later in this chapter, brief documentation of both WEAP and IWRMSD is given and compared to the work done in this thesis.

2.2 DYNAMIC NATURE OF WATER RESOURCES

One of the most important characteristics of water resources systems is that they are dynamic in nature. Water resources and demands behave in a way such that the interactions between them as well as among resources and among demands themselves create the overall performance of the system. Any slight change in one resource or demand might have some effect on other system components. In order to secure satisfactory real representation of the system, studies prior to model design must be carried out to grasp the dynamics of the water resources system under study and to identify all possible interactions among the system components.

Dynamic behavior in water resources systems can take many forms. Independent dynamic behavior of water resources system components occurs due to an internal variation within the component with no effect from an external agent. Resource variation with time such as river flows or groundwater storage are examples of independent dynamic behavior. Other forms of dynamic behavior such as the interaction between surface and groundwater, return flow from demand sites to resources, and water recycling in more than one demand are forms of dependent dynamic behavior. In these cases, there is always one or more factors that affect the water resources system component and causes the change.

2.3 OBJECT-ORIENTED MODELING

Skillful modeling in any field requires achieving two conflicting objectives. The first objective is to create a model that is complex enough to have an accurate representation of the real world. The second is to make the model as easy as possible to use. Object-oriented modeling is a methodology which describes real-world system by identifying system components, component behavior, and relationships among components (Tisdale, 1996). The basic element in object-oriented modeling is the "Object." The dictionary definition of an object is: "Anything perceptible by one or more of the senses, especially something that can be seen or felt; a material thing" (Morris, 1981- sited by Bourne, 1992). However, in object-oriented terminology an object can also represent a conceptual abstract. Objects are arranged into classes. An object class is a generalization of a group of objects that inherits some properties.

The object-oriented modeling has four basic characteristics; abstraction, encapsulation, inheritance, and polymorphism. Abstraction is the act or process of separating the inherent qualities or properties of something from the actual physical object or concept to which they belong. Encapsulation refers to capturing the state and behavior of an object entirely within the object. Inheritance is the ability of an object to obtain information about its internal states and methods from more abstract ancestors. Polymorphism refers to the capability for different objects to respond to the same meaning of a message sent by another object (Bourne, 1992).

Object-oriented modeling has many advantages over traditional modeling approaches. It facilitates creating a code that is transparent, reusable and extendible. Complex systems representation is easier using object-oriented decomposition of a system into its basic components and identifying the properties of each. A detailed discussion of object-oriented modeling is presented in Chapter 3.

Applications of object-oriented methodologies in the field of civil engineering are still limited. Foo and Akhras, (1994) used an object-oriented methodology for creating a prototype for the purpose of maintenance of timber trusses. Turk et al., (1994) also used the methodology for designing reinforced concrete buildings. Fewer applications are available in the field of water resources and hydrology. Behrens, (1991) developed an object-oriented artificial intelligence approach for river basin operation. Palmer, (1993) suggested making use of object-oriented modelling environments in water resources planning and management. He tried to demonstrate the advantages of the STELLA II object-oriented modeling environment over traditional programming languages such as FORTRAN using the High Aswan Dam in Egypt as an example. Solomatine, (1996) introduced an object-oriented modeling architecture for hydraulic systems. The South Florida hydrologic system was also analyzed by Tisdale, 1996, using object oriented methodology. Finally, the Nile Water Strategic Research Unit in Egypt developed an integrated water resources model for the whole country using an object-oriented approach (NWSRU, 1996, Simonovic and Fahmy, 1997, and Simonovic et al., 1997).

2.4 WATER RESOURCES POLICY MODELING

Modeling activities concerning water resources systems are among the leading applications of computer modeling for system management problems. Analytical and computer based models can be of great value for the decision making process. Suggested policies for future system management of water resources systems can be simulated using models and all the unfavorable consequences that might turn out to the system in the real world can be foreseen and thus avoided.

The main concern of water resources policy models is to test the short and long term effects of the decisions taken, or to be taken, by water resources decision makers. The scope and level of detail of each model vary according to the system under investigation. Not too many water resources policy models are documented in the literature. However, one of the most known models, the WEAP, presented in detail below, concentrates only on the water quantity and quality with insignificant focus on environmental and economic aspects. Other models, such as IWRMSD, also presented in this chapter take an approach similar to the one used in this thesis which includes economic, social, and environmental aspects of water resources policy modeling.

2.4.1 WEAP (WATER EVALUATION AND PLANING SYSTEM)

This review of WEAP is based on two publications. The first by Raskin et al. (1996) provides an explanation of each of the components of the program, inputs, and calculation algorithms used. The second publication is an application of WEAP to the Upper Chattahoochee River Basin in Georgia by the US Army Corps of Engineers (USACE, 1994). This publication illustrates the capability of the WEAP program to account for all supplies and demands in a water balance system, and provides WEAP users with a document to illustrate how the program is applied to a multi-use watershed with a major river and reservoir and, to offer observations on the application.

The WEAP system is a generic program for evaluating water policies and developing sustainable resource plans. WEAP aims to incorporate other values in water development plans such as emphasizing resource conservation, demand management, water use efficiency, and social, cultural, and environmental impacts of water resources development.

WEAP operates on the principle of water balance accounting. For both demand and supply components alternative sets of conditions can be tested and evaluated. The program gives the picture of the whole system according to the decisions taken, which allows the investigation of the impacts of present and future proposed actions.

The design of WEAP is guided by a number of methodological considerations. These considerations are:

1. **Integrated Planning Framework**: WEAP evaluates the water resources system as an integrated system. It integrates demands and supplies, water quantity and quality and, economic development and environmental constraints.

2. **Scenario Approach**: It is possible to include scenarios for different policies starting from the *Base Case*, which represents the current conditions. This technique can help answer What-If questions and can evaluate the effects of different policies on the economy and the environment.

3. **End-use and Demand-Driven**: WEAP allows the disaggregation of water demands to the degree that the data availability permits. Moreover, the program gives the freedom to choose the hierarchy for disaggregation.

4. **Environmental Effects**: WEAP provides a summary of the environmental pressures, like water quality degradation, for each scenario based upon loading coefficients.

5. **Ease of Use**: One of the main objectives in developing WEAP is to introduce a user friendly, easy-to-use model that can assist the decision making process. This objective is achieved by providing an interactive user interface that support the user with guidance.

6. **Modular Structure**: WEAP consists of a set of linked modules that interact together. Figure 2 shows the main modules in WEAP. The next section includes an explanation of each of these modules.

2.4.1.1 WEAP Modules

1. **Setup Module**: The setup module characterizes the application by defining the study area, the time horizon, and the physical components of the system along with their spatial relationships. Four basic types of physical components are available: 1) demand sites, as water use locations; 2) local supplies, defined as the independent water supplies that can be operated separately; 3) rivers and nodes, that represent the river basin system with all control structures and; 4) wastewater treatment plants, which process wastewater from demand sites before returning water to local supplies or river nodes.

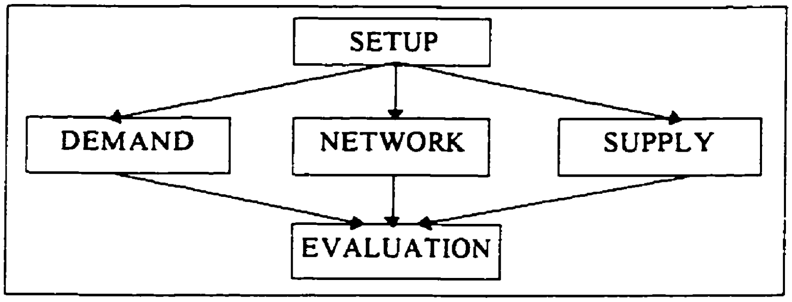


Figure 2: Modular Structure of WEAP (*Raskin et al., 1996*)

2. **Demand Module:** The demand module simulates the annual water demands for various final water services defined in the study. It also tracks pollution loads generated from demand sites. In order to define the demand tree, four levels of demand disaggregation are available, namely: sectors, subsectors, end-uses and, devices. WEAP does not require a rigid form of data. Rather, the structure of the demand tree can be adapted to the nature of the problem and the available data.

Future demands must be defined in the demand module. Three methods for forecasting future demands are available; interpolation, growth rate, and drivers and elasticities.

3. **Network Module:** The network module has three main functions; 1) preparation of the annual water demands at demand sites developed by the demand program for the monthly allocation in the supply program, 2) description of the wastewater flows, including pollution, from the demand sites and, 3) specification of the capacities of transmission links, and allocation of demand sites and wastewater treatment plant outflow links.

The network module accepts the monthly variations in water demands in order to convert annual demands to monthly demands. This module also accounts for losses of water either due to the efficiency of water use at demand sites or losses in the distribution network.

4. **Supply Module:** The supply module allocates available supplies to demand sites. The program calculates monthly water supplies over the planning period and simulates monthly river flows. In this module, the characteristics of each of the water supply sources are defined, and interactions between surface and groundwater are set up.

Priorities have to be set in case there are multiple sources for one demand or multiple demands to be filled from the same source. In the first case, the source that has the highest priority is selected for water supply until it is exhausted then the next in priority is chosen and so on. In the second case, complete satisfaction of the highest priority demand is fulfilled followed by the next in priority.

Operation and maintenance costs are among the possible entries to the supply module. Also, costs for improving resources can be included as capital costs. It is recommended to use only the costs that vary with different scenarios so that the comparative analysis can demonstrate the change in costs for scenarios.

5. **Evaluation Module:** The evaluation module compares physical and economic indicators between any two scenarios based on the results obtained from the demand, network and, supply modules. WEAP is designed so that it can produce various means of comparisons. The first type is the physical analysis of the system which is concerned

with water quantities used from each source along with water quality analysis. The second type introduces the cost streams. It compares the annual streams of cost incurred in both scenarios. The third type of evaluation is the benefit-cost analysis. It calculates the net present value (NPV) for both scenarios which are discounted according to a specific rate.

2.4.2 IWRMSD

(Integrated Water Resources Model for Egypt's Sustainable Development)

The main objective for developing IWRMSD is to create a flexible computer-based tool for Egypt's water resources management and strategic planning. The economic development and rapid population growth that the country is facing are putting pressure on the existing water resources. The need for this kind of model has become necessary under the current conditions of increasing water demands. This review of IWRMSD is based on many publications about the model such as NWSRU (1994, 1996), Simonovic et al (1997), and Simonovic and Fahmy (1997).

In order to overcome the shortcomings in water resources planning and management in Egypt, The Ministry of Public Works and Water Resources, MPWWR, initiated the Nile Water Strategic Research Unit, NWSRU, in 1994. The task assigned to NWSRU was to carry out a research project that tries to establish a new way of looking at the water future. The objective of this research is to develop strategic water planning methodology for Egypt's development in the 21st century. This methodology should account for different, non-traditional, aspects such as the following:

- continuity of water demand and supply projection over time.
- uncertainty of natural phenomena, and technical development.
- possible demand scenarios
- possible supply scenarios
- economic impacts
- environmental impacts
- social impacts
- political impacts
- water shortage mitigation strategies.
- high flood mitigation strategies (NWSRU, 1994).

2.4.2.1 Modeling Framework

The modeling process for IWRMSD is based on three main principles: object-oriented modeling, water-use-oriented approach and, hierarchical decomposition approach.

i) **Object-oriented modeling:** The complex water resources system in Egypt requires an interdisciplinary and multi-sectoral approach. An object-oriented approach is well suited for addressing complex management problems with multiple inputs and outputs. This approach allows consideration of all relevant issues without preventing future modifications.

ii) **Water-use-oriented approach:** The framework uses the water-use-oriented approach by building the model around main water use categories such as agriculture, domestic, industry, etc. This approach is recommended because of the intensification and development in the water use sector in order to respond to increasing population needs.

iii) **Hierarchical decomposition approach:** Egypt's water resources system requires an organized and focused research effort to deal efficiently with the complexity of the domain knowledge. This approach divides the effort into several tasks. Five water use categories form five sub-models to be integrated into one model.

2.4.2.2 Model Description

The result of the research activities carried out by NWSRU is the IWRMSD model 'Integrated Water Resources Model for Egypt's Sustainable Development.' The model presents a flexible planning tool for Egypt's water resources system. Five water use sectors namely agriculture, industry, domestic, navigation, and power generation are modeled separately in sub-models and integrated and connected together in a single model.

1. **Agriculture Sector:** Regardless of the variations in agricultural water requirements from one region to the other, this sector considers Egypt's old agricultural land as one region with weighted average values for crop water requirements. New land to be used for agriculture is considered as a separate sub-model. The reason for this distinction between old and new land is the difference in irrigation efficiency which depends on the soil type and irrigation techniques. The main output of this sub-model is the water required for agriculture for both old and new land. This sub-model also calculates some necessary indicators such as cultivation costs, revenues, required employment, and the rate of sufficiency from the main crops of wheat, rice, and vegetables.

2. **Domestic Sector:** This sector calculates the net water withdrawal to be used for domestic purposes. The calculations take into account the opportunities to expand the distribution

network and possible increase in per-capita water requirements due to an increase in the standard of living. Losses from the distribution network are also considered. Returned sewage flow can be either treated for recycling or disposed of in drains to the sea. Costs, revenues, and employment for this sector are estimated. Pollution loads for ten types of sewage water pollutants are calculated for the untreated sewage water.

3. **Industrial Sector:** Ten major industries are included in the industry sub-model. Water requirements for each type are estimated according to the production level. In addition, revenues and employment are calculated. Effluent water pollution loads are estimated to calculate the annual pollution load from industry.

4. **Power Generation:** This sector is not considered among the major water consumption sector. Two divisions are available: hydropower and thermal power. Hydropower is a water consumptive use as there is no water released only for hydropower. Thermal power stations use water for cooling purposes and return it with no significant change in quantity or quality.

5. **Navigation Sector:** This sector is also considered a non-consumptive water use sector as it uses the water released for other purposes. The navigation sector consists of two main types: transportation and tourism. For each type, water consumption, employment, and economic returns are calculated.

6. **Water Balance Sector:** The water balance sector aggregates all water sources on one side and water demands on the other side. Priorities are given to water demands according to

importance. Domestic water has the highest priority followed by industrial and agriculture. Return flows to be recycled from all uses are carried to the sources side.

2.4.3 COMMENTS

2.4.3.1 Comments on WEAP

The WEAP program offers a remarkable degree of flexibility for water resources policy analysis. It facilitates the process of testing various water management policies and estimates their effects in terms of economic indicators such as the NPV or environmental indicator such as water quality. The program is able to hold comparisons between scenarios and show the advantages of one to the other. The variety in the output forms available gives the most common forms for output for evaluation.

WEAP deals with water resources systems in a dynamic manner. It considers future changes in the system for all supplies and demands. The interaction between supplies and demands is also represented in different forms. One type of interaction is the return flow from demand sites to either local supplies or river nodes. Another example is the possibility to identify the relationship between the surface and groundwater.

WEAP is not designed to give solutions to water resources problem. Rather, it gives the decision maker the chance to introduce his/her own ideas into the system and test their effects. Although the output is detailed to some extent, the flexibility to arrange exactly what is needed in an output report form is not possible. Finally, WEAP is considered one step towards the new perspective of water resources modeling of having transparent and interactive models for policy analysis.

2.4.3.2 Comments on IWRMSD

This model creates a general picture for the country throughout the planning horizon. Due to the nature of integrated models, it was necessary to aggregate many components into one component. For example, the agriculture sector considers Egypt as one region while the total area can be divided into five different regions based on water consumption and crop productivity. Although the techniques used in aggregation gave good results when tested for available data, results could not be very reliable for future conditions. Another problem which arose when developing the model was the lack of reliable data. For some of the model components it was almost impossible to access the required data due to either a high level of bureaucracy, unreliability of available data, or unavailability of data. For these components, some arbitrary values were reasonably assumed to fill the data gap. Future development of the model should consider finding these data items and incorporating them into the model.

The IWRMSD presents the status of the water resources system in the future due to the application of suggested development plans for both resource and demand sides. The model does not consider any modification of the development plans while running. Rather, it shows the final result as the variation of water balance for the region throughout the planning period. The model shows whether the plans tested are applicable or not. The role of decision-maker is to make modifications to plans showing water deficit in the future and to re-run the simulation in order to make sure that all problems encountered by the system are eliminated.

The IWRMSD model presented here can be considered the first serious trial incorporating sustainable development criteria in the field of water resources planning and management in Egypt. Previous water resources models have concentrated only on water demand and supply and some of them have looked at water quality. This model is the first to consider socio-economic aspects as well as water quantity and quality. In addition, the dynamic look to the future gives more credibility to this model over previous ones. Dynamic simulation shows gradual change in system making the simulation more convincing and reliable.

2.4.3.3 The New Framework

The concepts used in developing the new framework do not differ much from those used for both WEAP and IWRMSD. The objective of analyzing water policies on an aggregate level is common among the three approaches. The object-oriented approach used for IWRMSD is considered the blue print for the new framework. In other words, this approach tries to fix some of the problems encountered using the IWRMSD approach. The major difference is the use of a feedback technique that enables the system to check the water balance in each time step and to apply some modifications to either resources or uses development plans in order to keep the water balance on the positive side.

CHAPTER 3

OBJECT-ORIENTED MODELING APPROACH

3.1 INTRODUCTION

Recent advances in computer hardware and software systems have contributed to the development of technology which is more easy-to-understand and utilize. One of the recent advances is the invention of Object Oriented Technology (OOT.) The OOT encompasses object-oriented programming languages (OOP), object-oriented development methodologies (OOD), object-oriented analysis (OOA), management of object-oriented projects, etc. This chapter presents an introductory explanation of the OOT basics and terminology. The concepts that should be used in designing an object-oriented application will be explained.

The term object-oriented is used to denote that a particular activity is done using a particular manner of thinking and organization that combines data and the processes which modify that data together into a single, functional unit. Object-oriented programming is a way of programming in which independent objects which contain their own data and processes interact to perform the operations of the program.

Object-oriented software is all about objects. An object is a black box which receives and sends messages. A black box actually contains codes (sequences of computer instructions) and data (information on which the instructions operate). In traditional programming languages, codes and data have been kept apart. For example, in the C language, units of code are called functions, while units of data are called structures. Functions and structures are not formally connected in C. A C function can operate on more than one type of structure, and more than one function can operate on the same structure. This is not so for object-oriented software. In OOP, code and data are merged into a single indivisible thing, an object.

3.2 SOFTWARE SYSTEMS

Software systems can be divided into two categories: simple systems and complex systems. Simple systems can be conceptualized, designed, and implemented by the same person. The level of complexity of such a system can range from very simple to relatively complex depending on the experience of the responsible person. In complex systems however, it is much more difficult for one person to handle all the problem solving requirements alone. Usually, a team of software developers and programmers work together toward achieving the final objective. Moreover, complex systems need good communication among developers and programmers.

In order to bring an order to a complex system, Booch suggests the following three techniques (Booch, 1994):

i) **Decomposition:** Complex system can always be decomposed into smaller parts (subsystems) which are easier to handle individually. Decomposition of complex systems facilitates the clear identification of the behavior of each of the subsystems. Interrelationships among subsystems of the main complex system must be defined as well.

ii) **Abstraction:** Depending upon the problem at hand, some inessential details of a complex system can be ignored. This technique must be used with great care in complexity handling. Ignoring some of the system details may cause the application to give misleading results.

iii) **Hierarchy:** It can be useful to define the complex system components in the form of hierarchy. Two types of hierarchy are defined: object structure and class structure. Object structure defines objects as "part of" the whole system. Class structure assumes that each object "is a" specific kind of a more general group of objects.

3.3 DEFINITIONS

i) **Object-Oriented Analysis (OOA):** Object-oriented analysis is a method of analysis that examines requirements from the perspective of the classes and objects found in the vocabulary of the problem domain.

ii) **Object Oriented Design (OOD):** Object-oriented design is a method of design encompassing the process of object-oriented decomposition and a notation for depicting both logical and physical as well as static and dynamic models of the system under design.

iii) **Object-Oriented Programming (OOP):** Object oriented programming is a method of implementation in which programs are organized as cooperative collections of objects, each of which represents an instance of some class, and whose classes are all members of a hierarchy of classes united via inheritance relationships.

OOA is the first task toward developing an object-oriented model. The output of the OOA is used to start an OOD. Output from the OOD stage can be used as a blueprint for implementing a system using any of the OOP methods.

3.4 ELEMENTS OF THE OBJECT MODEL

The object model is the collection of principles that form the foundation of object-oriented design. The object model has four basic elements: abstraction, encapsulation, modularity, and hierarchy.

3.4.1 ABSTRACTION

An abstraction denotes the essential characteristic of an object that distinguishes it from all other kinds of objects and thus provides crisply defined conceptual boundaries, relative to the perspective of the viewer (Booch,1994.) An abstraction focuses on an outview of an object and separates an object's essential behavior from its implementation. The core of object-oriented design step is deciding on the right set of abstractions for the problem domain.

3.4.2 ENCAPSULATION

Encapsulation is the process of compartmentalizing the elements of an abstraction that constitute its structure and behavior. It serves to separate the contractual interface of an abstraction and its implementation. Abstraction and encapsulation are complementary concepts. While abstraction focuses on the observable behavior of an object, encapsulation focuses on the implementation that gives rise to this behavior.

3.4.3 MODULARITY

Modularity is the property of a system that has been decomposed into a set of cohesive and loosely coupled modules. For large applications, it is better to use a number of separate modules which, when connected, form the overall system's physical structure. Modularity allows the reduction of software development time and cost, as it enhances the development and revision of each module independently.

3.4.4 HIERARCHY

Hierarchy is the ranking or ordering of abstractions. In any system, the set of abstractions always forms a hierarchy. Identifying these hierarchies helps greatly in understanding the problem. Two basic types of hierarchies are identified: the class structure and the object structure. Class structure considers the objects as a subclass of a more general class. Class structure highlights common structure and behavior within a system. Object structure considers the more general class which consists of more specialized classes. It illustrates how different objects collaborate with one another through patterns of interactions (mechanisms).

3.5 TERMINOLOGY OF AN OBJECT-ORIENTED MODEL

3.5.1 OBJECTS

Objects are the physical and conceptual things that can be found all around the universe. Every single entity can be defined as an object. The selection of objects to be considered for a model depends on the nature of the system under consideration. Each object has a state. The state of an object represents its conditions or set of circumstances describing the object. In order to eliminate the complexities that might appear when trying to find a state for one complex object, only possible states of the object that have some relevancy to the model are considered.

Most of the objects have a static state which can never be changed by itself. This kind of object requires an external factor to request the object to change its state. On the other hand, objects capable of changing their states spontaneously are called "Active Objects." A clock object can be considered a good example of an active object. Each object in an OO model should have an identity. Object identity is the property that distinguishes it from all other objects. The identity of an object should be reserved for the whole lifetime of the object even if its state is changed.

An object's behavior depends on many variables such as its state and the operation performed upon it. Thus, the object state represents a cumulative resultant of its behavior. Operation performed on an object can be in the form of modifying of the model state, accessing the state, initializing the state, or nullifying the state of the object. In order for a static object to change its state, a message from another object should be sent through a link. Links are defined as the physical or conceptual connections between objects. An object can be categorized according to its links as follows:

- actor : an object that can affect other objects but never affected by any object,
- server : an object that can never affect other objects, but affected by other objects,
- agent : an object that can affect and be affected by other objects.

3.5.2 CLASSES

As defined by Booch (1994), the class is a set of objects that share a common structure and a common behavior. In another definition, the class is a pattern, template, or a blueprint for a category of structurally identical items (Berard, 1996.) Using classes, complex problems can be decomposed into smaller elements by partitioning them into different elements of design.

Each class has an outside and inside view. The outside view of a class is called "the class interface." The class interface provides an abstraction of the class while the inner structure and behavior are hidden. The interface of a class consists of three parts

- public : a declaration that is accessible to all clients,
- protected : a declaration that is accessible only to the class itself and its subclasses,
- private : a declaration that is accessible only to the class itself.

The inside view of a class is called "the class implementation." The class implementation contains all the behavior "secrets" of the class. Usually, it encompasses all the operations defined in the class interface.

Classes can be connected through many types of relationships. The most important relationship among classes is called "*association*." Structuring associations among classes begins at an early stage of analysis and design. The process of identifying class' associations shows the interdependencies among model abstractions. *Inheritance* is another relationship where one class shares the structure or behavior of one or more other classes. Inheritance is a sort of hierarchy where subclasses inherit the characteristics of more generalized classes. Another type of relationship is *polymorphism*. Polymorphism is a concept in type theory wherein a name may denote instances of many different classes as long as they are related by some common superclass (Booch, 1994.) Polymorphism can be useful when there are many classes sharing the same protocol. Many unnecessarily repeated statements can be eliminated from the model as each object implicitly knows its own type.

3.6 QUALITY OF THE ABSTRACTION

The quality of an abstraction is the measure of goodness and completeness of a modeling process. Booch, (1994) suggests the following five metrics for measuring abstraction quality: coupling, cohesion, sufficiency, completeness, and primitiveness.

3.6.1 COUPLING

Coupling is defined as the measure of the strength of association established by a connection from one class to another. Strong coupling complicates a system since a class is harder to understand, change, or correct itself if it is highly interrelated with other class. Complexity can be reduced by designing a system which has the weakest possible coupling between classes. However, there is tension between the concepts of coupling and inheritance, because inheritance introduces significant coupling. On one hand, weakly coupled classes are desirable; on the other hand, inheritance, which tightly couples superclasses and their subclasses, helps users to exploit the commonality among abstractions.

3.6.2 COHESION

Cohesion measures the degree of connectivity among the elements of a single class or object. The most desirable form of cohesion is functional cohesion, in which the elements of a class all work together to provide some well-bounded behavior. Thus, the class reservoir is functionally cohesive if its semantics embrace the behavior of a reservoir, the whole reservoir, and nothing but the reservoir.

3.6.3 SUFFICIENCY

Sufficiency means that the class captures enough characteristics of the abstraction to permit meaningful and efficient interaction. For example, if one is designing the class Set, operations both to remove as well as add an item should be included. Neglecting one of them violates the sufficiency.

3.6.4 COMPLETENESS

Whereas sufficiency implies a minimal interface, a complete interface is one that covers all aspects of the abstraction. A complete class is thus one whose interface is general enough to be commonly usable to any client. Completeness is a subjective matter, and it can be overdone.

3.6.5 PRIMITIVENESS

Since many high-level operations can be created from low-level ones, It is also suggested that classes should be primitive.

3.7 OBJECT-ORIENTED MODEL DEVELOPMENT

A model is a representation of a real system for the purposes of understanding and testing the system before implementation in the real world. Real world systems are represented physically by models which are scaled down or up, or mathematically by using functional relationships. Object-oriented modeling abstracts the components from the real world and simulates their interactions. Methodologies for developing an object-oriented model have been an attractive subject to computer programming specialists. Rumbaugh et al. (1991) developed a methodology called "Object Modeling Technique" (OMT). Dillon and Tan (1993) proposed a methodology called "The Process Of Development Of An Object-Oriented Conceptual Model -- Object-Oriented Analysis." The following subsections briefly introduce both.

3.7.1 OBJECT MODELING TECHNIQUE (RUMBAUGH ET AL, 1991)

The object modeling technique (OMT) divides the modeling development process into three main stages; the object model, the dynamic model, and the functional model. The interconnections among these three models should be limited and explicit in order to create a good design in which the coupling introduced in the model is minimal.

3.7.1.1 The Object Model

The object model describes the structure of objects in the system. It represents the static, structural data aspects of the system. The object model is the base for the other two models, the dynamic and functional. The process of developing the object model begins with the identification of the objects and their arrangement into classes within the problem domain. The selection of objects and classes is very dependent on the problem at hand so that real world components are present in the model. This step must address all objects' properties such as their attributes, operations, and methods. The second step consists of establishing the relationships among objects and classes. Links are the physical or conceptual connections between objects. Links can be grouped into associations that describe a group of links with a common structure. The next step in developing the object model is the identification of the generalizations and inheritances among the objects and classes. Generalization is the process of relating a class to a more general class of the same type. The more generalized class is called a *superclass*, while the less generalized is a *subclass*. Subclasses are said to *inherit* features from their superclasses. Generalization facilitates the modeling process by structuring classes capturing the similarities and differences among them. The final step is grouping the object model classes into smaller modules. This technique enables the programmer to partition the object model into manageable pieces.

3.7.1.2 The Dynamic Model

The dynamic model is concerned with the changes in the model objects' states overtime. Two major concepts that cause dynamic changes in the model are events and states. An event is an external stimulus that forces objects to change their states. A state is the value of the object. The object's response to an event received from another object depends on the state of the receiving object. In response to an event, the receiving object may change its state or send another event to the sending object or any other object. For every class, a state diagram representing the states, events, and state transitions should be represented. The dynamic model consists of a collection of state diagrams for all classes that work together to perform the dynamic behavior of the system.

3.7.1.3 The Functional Model

The functional model contains all the computations and functional derivations of the data values. The functional model describes what happens to the objects regardless of the time or sequence of computations. Specifying the time and sequence in computations is directly related to the dynamic model. The basic function of this model is to show the transformation of the input and stored data into the model output. The functional model consists of multiple data flow diagrams (DFD) showing the functional relationships of the values computed by a system. The DFD is a graph showing the flow of data values from their sources in the objects through processes that transform them to their destinations in other objects.

3.7.2 Development Of An Object-Oriented Conceptual Model (Dillon and Tan, 1993)

This methodology consists of three major tasks. The first task is the development of the natural language for the problem under consideration. Usually this first identification of the problem does not address all the details of the problem or the system being analyzed. It is useful in narrowing the area to be considered and in focusing attention.

The second task introduces six major steps to be followed in order to create an object-oriented conceptual model. These steps are:

a) identification of concepts, classes, and objects;

b) identification of the structural relationships and constraints for the classes and objects;

c) identification events and messages and their allocation to particular classes and objects;

d) identification of the required external behavior and their association with particular objects and classes;

e) identification of the internal static structure of objects and classes, namely attributes and static constraints;

f) identification of the internal dynamic structure of objects and classes, namely actions/methods and dynamic constraints.

The third and final task is design and implementation. The process of design and implementation is highly dependent on the software language to be used in the model as well as the system's designer. In some cases, the designer is restricted to use the existing systems and software tools.

3.8 OBJECT-ORIENTED PROGRAMMING LANGUAGES

During the last decade there has been tremendous advancement in OOP languages. Some of the languages have been developed from traditional programming languages, such as C++ as an OO version of C, and others are brand new as OOP languages. This section gives a brief overview of some of the most popular OOP languages.

3.8.1 C++

C++ is an object-oriented version of C. It is compatible with C (it is actually a superset), so that existing C codes can be incorporated into C++ programs. C++ programs are fast and efficient, qualities which have helped make C a very popular programming language. C++ sacrifices some flexibility in order to remain efficient. However, C++ uses compile-time binding, which means that the programmer must specify the specific class of an object, or at the very least, the most general class to which an object can belong. This makes for high run-time efficiency and small code size, but it trades off some of the power to reuse classes.

3.8.2 SMALLTALK

Smalltalk is a pure object-oriented language. While C++ makes some practical compromises to ensure fast execution and small code size, Smalltalk makes none. It uses run-time binding, which means that nothing about the type of an object need be known before a Smalltalk program is run. Smalltalk programs are considered by most to be significantly faster to develop than C++ programs. A rich class library that can be easily reused via inheritance is one reason for this. Another reason is Smalltalk's dynamic development environment. It is not explicitly compiled, like C++. This makes the development process more fluid, so that "what if" scenarios can be easily tried out, and classes' definitions easily refined. However, being purely object-oriented, programmers generally need longer to master Smalltalk than C++. Most of this time is actually spent learning object-oriented methodology and techniques, rather than details of a particular programming language. In fact, Smalltalk is very simple, much more so than either C or C++.

3.8.3 JAVA

Java is the latest, flashiest object-oriented language. It has taken the software world by storm due to its close ties with the Internet and Web browsers. It is designed as a portable language that can run on any web-enabled computer via the computer's Web browser. As such, it offers great promise as the standard Internet and Intranet programming language. Java is a curious mixture of C++ and Smalltalk. It has the syntax of C++, making it easy (or difficult) to learn, depending on one's experience, but it has improved on C++ in some important areas.

3.8.4 STELLA II

Recently a number of commercial generic simulation tools that can be readily used for object-oriented modeling have been developed. Among these tools are STELLA II™ (High Performance Systems, 1992) and Vensim® (Ventana Systems, 1993). These tools provide decision makers with limited computer training like water resources planners with a graphical, object oriented environment that allows them to quickly construct, and easily interact and perform system simulations, then present results clearly to wider audiences. In general, model developing through such environments takes less effort, computer knowledge, and time, since the internal consistency of the simulation models is checked automatically. The use of object-oriented programming modeling environments has allowed better understanding of the potential advantages and disadvantages created by the development of water resources projects or their operation (Fahmy and Aboelata, 1995).

3.8.4.1 STELLA II Basic Model Building Blocks

STELLA II gives a variety of building blocks to be used in model development. Each of these building blocks is designed to perform a specific function. The main building blocks are stocks, flows, and converters. Links between model components are denoted as "connectors". The following section explains the functions and usage of each building block.

a) **Stocks:** Stocks represent acummulation processes in models. One type of stock object, called Reservoir, has its own built-in mass-balance equation. Along with the flows associated with any stock object, it can represent any system that has a cumulative nature such as a dam or a reservoir. Stocks can serve as resources. Such resources can be finite if they don't have an inflow supply or, limited if there are limited supplies in the form of an inflow object. Other types of stock objects, such as conveyor, ovens, or queue, do not have significant use in the water resources field.

b) **Flows:** The flow icon is used to represent the physical components whose values are expressed as rates for a given time period. The three types of flow icons are inflow, outflow, and biflow. The flow rates may be constants, a function of time, a function of any other component of the system, or a graph (discrete or continous time series). The flow icons may represent finite or infinite flow depending on the way they are hooked to the stock. If the flow icon lies between two stocks then it is considered as a finite flow icon or a controlled linking channel. If the flow icon is connected to a stock icon from only one end, the other end is considered either infinite sink or source and in this case, the free end is displayed as a cloud. It should be noted that all flows within Figure 3 are of an infinite nature.

c) **Connectors:** Connectors are the means of illustrating dependency among model components. They connect any two objects in a way such that the value of the object at the connector head is directly affected by that of the object at the connector tail. When appearing in a model, the independent object should include, in its defining equation, all the dependent objects.

d) **Converters:** Converters can be considered as the external objects that can affect, or be affected by, the model performance. Converters represent either a model's parameter as an input or, an indicator as an output. These converters are connected to the model's main components using connectors.

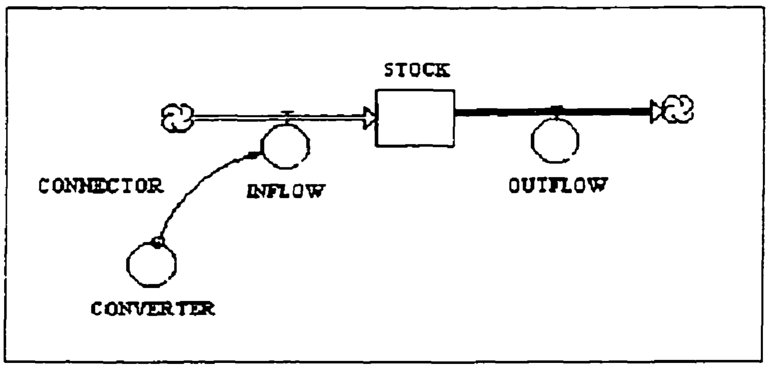


Figure 3: STELLA II Model Building Blocks

3.8.4.2 Data Entry

Three different types of data entry are available through the STELLA II environment. The first type of data entry assigns a constant value to a variable represented by an object. The value of the constant is entered directly through the configuration window of the object and can be changed each time through the configuration window or through setting the required value using the slider object that appears in the display. Sliders are objects in STELLA II that allow the user to move the scalar value of a variable or parameter between minimum and maximum values.

The second type of data entry is actually coding or programming the object's behavior during the simulation through a form of data entry. The object's behavior is the equation of the physical law that governs the variable value and defines its relation with other variables. The difference between coding in the STELLA II environment and coding with any other traditional language is the simplicity. All the users have to do is write a mathematical equation and in some cases an "IF . . . THEN . . . ELSE" statement. On one side of the configuration window of the each object, one can find the object or variables that ought to be included in expressing the right-hand side of the equation. In other words the user does not need to know or remember what the topology of the model is. On the right side of the window, a list of built in mathematical functions in the STELLA II environment is provided to the user to facilitate the coding process. Another list of numbers and operators is provided in the same window. The object's configuration window is self contained. It presents all the syntax tools needed to help the user to code with almost no information about the programming language.

The third type of data entry is in the form of graphical functions or relationship. This type can be carried out in two different ways. One way is to enter the data manually into the graph data entry window. In this case, the user must specify the number of data points as well as the maximum and minimum values for the independent variable of the relationship which can be time or any other system's variable. Based on the number of data points the model divides the range of the independent variable equally. Then, the user should enter the corresponding values of the dependent variable manually. Another method is to import the dependent variables' values from a database or from a spreadsheet software. In this case, the user is required to specify the range of the independent variable. It should be noted that in both cases the interval between data points is equal.

3.8.4.3 Model Output

One of the shortcomings in traditional programming is the inability to customize the model's output in the form required according to the purpose of the model usage. Once the output form is defined within the model structure, it is very difficult for ordinary model users or decision makers to make any changes in the specified output format without fully understanding the model code. This shortcoming is avoided in STELLA II. The program enables the ordinary model user to customize or even create a form for the model output and to change these formats as required.

The output from the simulation model can be presented using graphs, tables, or both. Graphs representing the model's output can be defined for STELLA II as a function of time, i.e., showing the change of the selected variable of the model as the simulation time proceeds, or plotting the relation between any two components of the model. The model user can also specify the scale of the graph. Creating a table is even easier. The table is defined by selecting variables, their precision, and the time interval between successive readings.

3.8.4.4 Sensitivity Analysis

Sensitivity analysis can be performed using STELLA II by specifying the range that the selected parameter might take along with the number of required runs needed in order to compare the model results. When running the model, STELLA II plots the different runs on one graph for the selected variable. This capability facilitates the decision-making process of choosing different alternatives and showing the effect of changes in the model parameters on different model variable. This option may be used during model calibration as will be explained later.

3.8.4.5 Model Modification

The STELLA II environment offers a number of features that allow the user to make any necessary changes in the simulation model. These changes can be made to the model's structure itself, to the mathematical formulation, or to the input data. After making the required modifications, the program checks for the consistency of the equations and the relations between all model components. If the program discovers any logical error in the equation relations or functions, a message declaring that error is displayed at the bottom of the configuration window.

If it is necessary to modify input data values or a mathematical equation, the user should double click on the object that contains such data to open up the configuration window.

Once the configuration window is open the user can start to edit the data or the mathematical formulation of the required variable. If a new object must be added to the model structure, the relation (connectors) of this object to other model objects must be established and defined. When removing an old object from the model, all its connections to other model objects are destroyed automatically and question marks appear on the objects that need modification in order to eliminate the removed object from their equations.

3.8.4.6 Model Calibration

In the STELLA II environment, only common trial and error calibration procedure can be carried out. Nevertheless, the sensitivity analysis feature in the STELLA II environment can facilitate and accelerate the trial and error calibration procedure. Users can specify a range and number of runs for a calibration parameter to check the sensitivity of the model output to the change of this parameter.

3.9 ADVANTAGES OF OBJECT-ORIENTED MODELING APPROACH

Object-oriented modeling is among the first modeling approaches to consider the flexibility and reusability of the developed code. Object-oriented modeling minimizes the efforts required to change a model either by additions or deletions. These characteristics of flexibility and reusability facilitate the model creation process and save both time and effort. Object-oriented programming also helps manage complexities within the modeled system by simplifying the process of structuring relationships among model components. Programmers can easily transfer objects from the real world into interrelated components of the model. If programming is viewed as simulation, it is much easier to pick objects out of the simulated world than it is to develop a programming solution based entirely on procedures and actions (Voss, 1991). Major advantages of object-oriented approaches can be summarized as follows(Berard, 1996):

- object-oriented approaches encourage the use of modern software engineering technology.
- object-oriented approaches promote and facilitate software reusability.
- when done well, object-oriented approaches produce solutions which closely resemble the original problem.
- when done well, object-oriented approaches result in software which is easily modified, extended, and maintained.
- there are a number of encouraging results reported from comparisons of object-oriented technology with more-commonly-used technologies.

The complexity of water resources systems has been a great obstacle for water resources planners in developing a clear understanding of the modeling process and in having confidence in the model's results. Object-oriented modeling gives water resources planners and decision makers the chance to participate in the modeling process without extensive computer programming experience. More concentration can be directed towards conceptualizing the model and understanding its embedded relationships, rather than trying to accommodate the model into the structured type of programming. The use of object-oriented programming in water resources planning and management produces models that are flexible to accommodate any changes within the system configuration or its operation policies. Representing real systems by interlinked components through graphical user interface, which is usually an inseparable part of any object-oriented environment, makes the model structure and its underlying assumptions transparent to any user (Fahmy and Aboelata, 1995).

CHAPTER 4

THE DEVELOPMENT OF WATER RESOURCES POLICY MODELING FRAMEWORK

4.1 INTRODUCTION

Water is one of the most important factors for human welfare in developing as well as developed societies. Sensible management of water resources has to satisfy an ever increasing demand, driven by population growth and changes in lifestyle, and at the same time meet an increasing set of constraints and concerns regarding environmental impacts and resource depletion and degradation.

All these driving forces of development, acting in concert and often reinforcing each other, require better and more efficient tools for decision support in planning and management. The management of water resources requires the integration of very large volumes of information from numerous sources, the coupling of this information with efficient tools for assessment and evaluation that allow broad, interactive participation in the planning, assessment, and decision making process, and effective communication of the results and findings to a broad audience.

Water resources management problems usually involve a mixture of natural science and engineering aspects, as well as socio-political and economic elements. While measurable phenomena and causal relationships characterize the former domain, the latter is better characterized by subjective or collective values and judgments, preferences, perceptions and expectations, and plural rationalities rather than a universally agreed upon guide. In the scientific and engineering domain, assessment also involves forecasting, designing and analyzing 'what – if' scenarios, which is an inherently difficult problem in almost any domain. Environmental and water resources management problems are complex and multi-disciplinary in nature. They involve the need to forecast future states of complex systems which are often undergoing structural change and are subject to sometimes erratic human intervention. This in turn requires the integration of quantitative science and engineering components with socio-political, regulatory, and economic considerations. Finally, this information has to be directly useful for decision making processes involving a broad range of actors. It seems obvious that no single method can address credibly and satisfactorily all these requirements.

However, methods that are based on modern information technology offer at least some of the necessary ingredients of effective information and decision support systems. The integration of techniques such as data base management, geographical information systems, simulation and optimization models, expert systems, as well as interactive, symbolic and graphical user interfaces, animated graphics, hypertext, and multi-media systems, seem to have the necessary power and flexibility to support water resources planning and management in practical applications.

The ultimate objective of computer based water resources management applications is to improve planning and decision making processes by providing useful and scientifically sound information to the public officials, planners and scientists, and the general public involved in these processes.

4.2 A NEW FRAMEWORK FOR WATER RESOURCES POLICY MODELING

The development of a new framework for water resources policy modeling using an object-oriented approach includes a number of interrelated tasks. These tasks can be summarized as follows:

1. abstract water resources system components (objects, classes, etc.)
2. identify interrelationships among system components.
3. develop future forecasts for the system (resources projections and demand scenarios.)
4. identify water resources system indicators.
5. identify types of problems that might affect the system in the future.
6. develop the problem solving mechanism.
7. design and create an object-oriented model.
8. apply the model to a case study.

The above mentioned tasks are the headlines for the framework. Within every task, sub-tasks that incorporate more details should also be carried out. Figure 4 shows

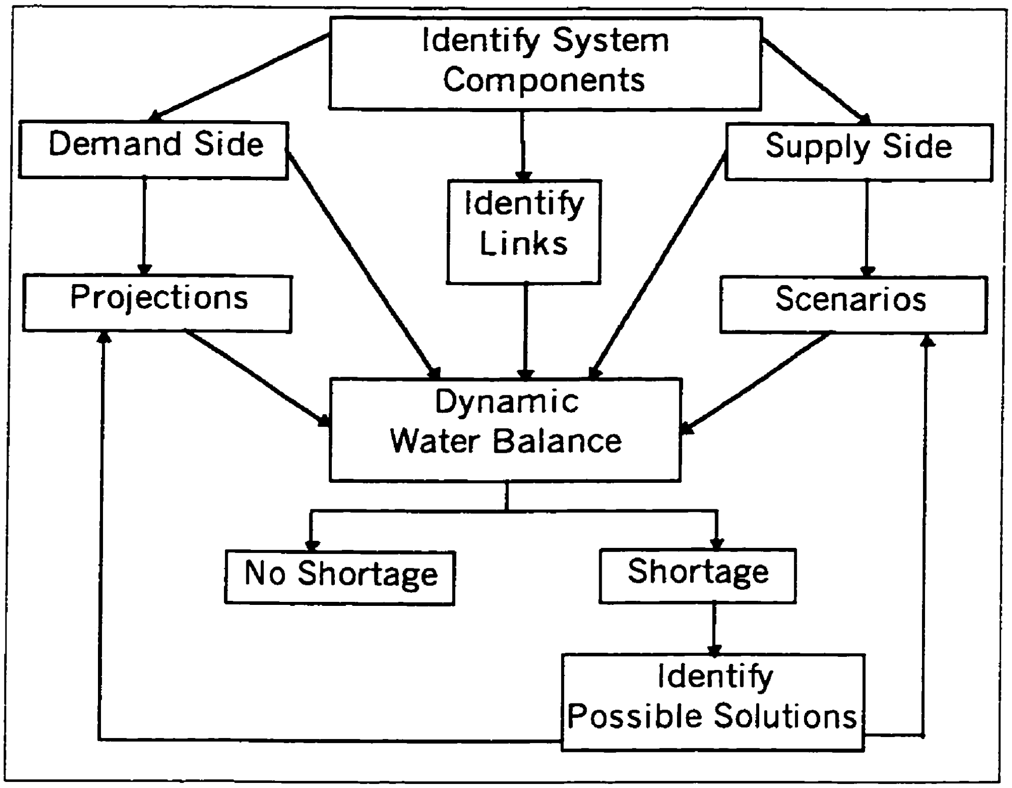


Figure 4: Water Resources Policy Modeling Framework

the modeling framework. The first task of the model is the identification of the water resources system components. Links between system components are identified. The dynamic behaviors of water sources and demands are described. The water balance between water resources and demands is checked for every time step. In the case of a positive water balance, the process proceeds to the following time step. In the case of a negative water balance, possible actions to overcome the shortage problem are checked and applied to the system. The following sections describe each of the framework stages.

4.2.1 GENERAL DESCRIPTION

4.2.1.1 Abstraction of Water Resources System Components

Water resources systems are complex in nature. Complexity comes from different sources such as the large number of interconnected physical processes, socio-economic-environmental impacts, dynamic change in quantity and quality of water resources system, spatial variability of characteristics, and the high level of uncertainty of input variables.

Components of water resources systems can be classified into two superclasses; the resources and the demands. The demands specify the needs for water while, the resources supply enough water to meet the demands at the pre-specified time and place. Water resources and demands can be grouped in a variety of classes depending on the characteristics of each water resource or use.

a) Water Resources

Water resources can be categorized into conventional and non-conventional water sources. Conventional sources are those which have been known and used for a long time such as surface water, groundwater or rain. Non-conventional water sources include those sources which have been newly developed to obtain water to overcome water shortage problems. Examples of non-conventional sources are drainage water reuse, sewage treatment, or desalination of brackish or sea water.

b) Water Demands

Water demands sector considers the integration of all water use sectors. Water uses can be categorized into two basic types; consumptive and non-consumptive uses. Consumptive water uses are those which consume water i.e. part of the water supplied is not returned to the system. Non-consumptive uses require that water be available in the stream while the same water can be used for other purposes.

4.2.1.2 Identification of Links

In order for the abstracted system components developed in the previous step to form a system, the links among components should be clearly defined. Links, as defined previously, are the physical or conceptual connections between objects. A link from one component of the system to another component denotes a specific function that cannot be carried out without the participation of both components. In water resources, links can represent the interdependencies of resources such as surface and groundwater interaction. They also represent the relationships that connect the supply and demand components in order to either control the distribution of water from resources to uses or to convey the return flow from uses in the resources sector.

4.2.1.3 Development of Future Forecasts

Water resources systems are dynamic in nature. Changes over time apply to both resources and uses sectors. For water resources, water quantities to be available from either surface water or rain are not constants. Forecasts using well-known methods such as regression can facilitate the expectation of the water quantities to be received. Water demands depend on the level of development in the region under study. The higher the rate of development, the more water needed to satisfy expansion requirements. New techniques to reduce the water consumption rate for different uses is also one of the factors that affects future water demands.

Future water demand scenarios can be developed by integrating the development plans for water use sectors and by estimating the required quantity of water for each use. Water demand scenarios should continuously show the change of the demand pattern for the planning period.

4.2.1.4 Identification of Water Resources System Indicators

One of the most important steps in this framework is the development of the system indicators. Indicators represent the state of the system and enhance judgments. As water is the back bone for development, water resources indicators can be social, economic, or environmental as long as the relationships of water to these sectors are well defined.

4.2.1.5 Identification of Types Of Problems

One of the objectives of developing a water policy model is to solve problems already existing within the system as well as problems that might develop in the future. Present problems can be identified by the experience gained throughout the history of the water resources systems, while future problems need a deep vision into the expected system behavior. Early identification of the type of problem makes it easier to find an immediate suitable solution for the problem without sacrificing system reliability.

4.2.1.6 Development of Problem Solving Mechanism

After finding the type of problems that may be encountered, a mechanism for solving these problems should be developed. The mechanism should clearly address all possible solutions to potential problems as well as the criteria by which one solution is chosen for implementation.

4.2.1.7 Design and Development of the Object-Oriented Model

The next step in the framework is integration of the results from all previous activities into an operational model. The process of design and development of a model depends on the person or team developing the model as well as the modeling tool selected for development. In some cases, the choice of the modeling tool is limited by budgetary constraints.

The model design and development process requires great attention and cooperation among system analysts who conceptualize the system model, the system designer who is responsible for code development, and the decision-makers who may be the potential users of the model. Cooperation among these three groups must be established throughout the modeling process so that the system is correctly represented by the model, and decision makers' requirements are satisfied through the model results.

The final stages in the model development are the calibration and validation processes. The purpose of the calibration process is to adjust the model parameters so that they reflect realistic system behavior. Validation process is used to ensure that the model is achieving appropriate results with different data sets. These processes are implemented by testing the model performance using historical data sets i.e. processing historical data through the model and comparing its output with the observed outcomes. The length of these processes depends on the number of parameters included in the system. The larger the number of parameters, the longer the time required for model calibration and validation.

4.2.1.8 Model Application

After making sure that the model is working properly, it can be applied to a particular problem domain case study. One of the advantages of the object-oriented modeling technique is its flexibility which allows for some modifications to the model to be able to accommodate any system conditions that were not available in the original model.

4.3 IMPLEMENTATION OF THE WATER RESOURCES POLICY MODELING FRAMEWORK

4.3.1 STAGE 1: SYSTEM COMPONENTS

4.3.1.1 Water Resources

Water resources can be categorized into conventional and non-conventional water resources. Conventional water resources are the most common water sources. They can be classified into surface water, groundwater, and rainfall. The need for additional water sources has led to use of non-conventional sources. The main classes of non-conventional water sources are drainage water reuse, sewage water treatment, and salt and brackish water desalination. The following sections describe conventional and non-conventional water sources.

a) Surface Water: Surface water can be defined as the water flowing, or stored, above ground level. Surface water constitutes the greatest percentage of the water accessible all around the world. In most countries, surface water, due to its low cost, has the first priority of use unless contamination levels prohibit its use for consumption purposes. Figure 5 shows an example of the hierarchy to be used in identifying the components of surface water classes and objects. In this Figure, surface water is divided into three classes: rivers, lakes, and control structures. Each of the three classes is further divided into more detailed sub-classes.

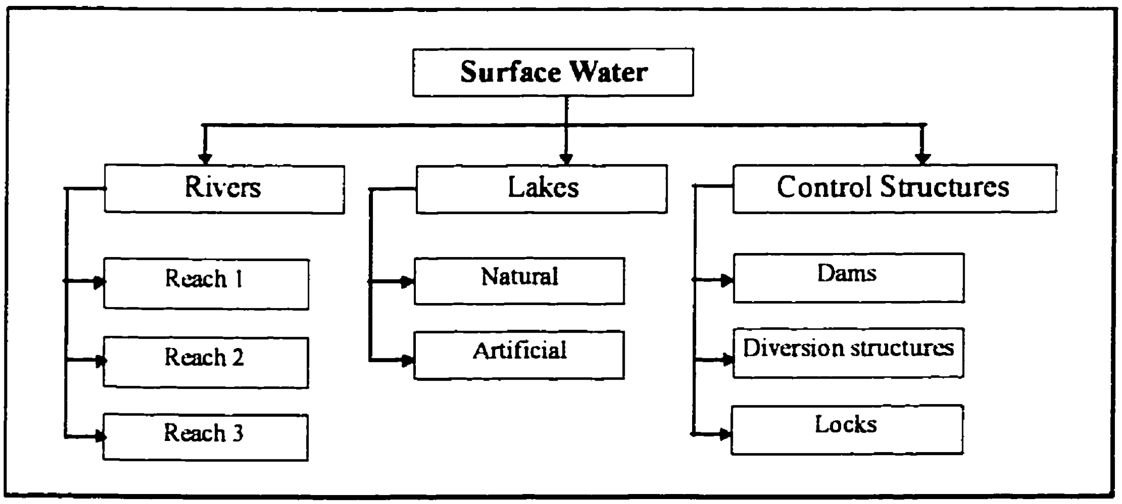


Figure 5: Surface Water Hierarchical Decomposition

Lakes and rivers are the sources of surface water. Natural and artificial lakes act as water storage areas during rain (high flow) seasons to be used during dry (low flow) seasons using control structures. Dams are water control structures that are able to store and release the required amount of water according to a well-defined operation policy.

Designing the operation policy of a dam requires a great amount of knowledge about characteristics of the system to be regulated using that dam. Other important elements to be considered for design are water requirements downstream the dam, forecasts for the coming years for both demand and supply, and the expected side effects of the designed policy.

Classes of Surface Water: Surface water can be represented by three main classes: rivers, lakes, and control structures. The following sections aim at disintegrating the basic classes of surface water into subclasses and pointing out the characteristics of each class or subclass. Then, the identification of objects under each class, or subclass, is introduced.

a-1) Class: Rivers: Rivers are the natural streams that convey fresh water either from lakes or from the accumulations of rain runoff through smaller channels. The nature of a river depends on:

- topography,
- climatic conditions, and
- geological conditions.

Subclass-Reach: The nature of a river itself might change from one stretch to another as it passes through different regions. In order to facilitate dealing with rivers, it is better to divide rivers into reaches. A river reach is a segment of the river that has the same characteristics concerning topography and climate, and bordered by either natural of artificial boundaries. Rivers may also be divided into reaches according to their use in each region.

Attributes of a River Reach:

- boundaries (start, end),
- inflow,
- slope,
- dimensions (length, average width, maximum and minimum water depth),
- stage-discharge curve,
- intakes,
- tributaries,
- local flows, and
- sediment load.

a-2) Class: Lakes: Lakes are the water storage elements in a water resources system. Lakes can be natural because of climatic and topographic conditions, or artificial by building control structures in water streams. Usually, artificial lakes are easier to control than natural lakes as their sites are pre-selected for optimizing water loss as well as minimizing the cost of control structures

Subclass-Natural Lakes: As mentioned above, natural lakes occur due to topographic conditions.

Attributes of a Natural Lake:

- water content,
- recharge rate,
- storage-elevation curve,

- storage-surface area curve, and
- water surface elevation variation range.

Subclass-Artificial Lakes: Artificial lakes are those which are created by building a control structure on a water stream. Blocking the water path causes the water level upstream the structure to rise and spread over an area which is dependent on the topography of the site.

Attributes of an Artificial Lake

- maximum capacity,
- storage-surface area curve,
- storage-elevation curve,
- losses (evaporation, seepage),
- storage zones (dead, live, flood control), and
- environmental conditions (water levels).

a-3) Class: Control Structures: Control structures are the man-made intervention to natural streams built in order to perform different functions. Usually, control structures have three basic functions; flood control, water discharge regulation, and power generation. The class-control structures can be divided into three subclasses; dams, barrages, and locks.

Subclass-Dams: Dams have a wide variety of functions to perform. Among the functions associated with dams are (Warren, 1968):

- flood control
- water supply
- irrigation
- seasonal storage
- over-year storage
- power generation
- fishing
- recreation.

Dams can be a single- or multi-purpose i.e. some dams may be constructed for only one of the above mentioned purposes, while others can serve more than one purpose. The selection of the dam site and type is highly dependent on the geological nature of the site, its geographical location, and the dam's purpose(s.) When the decision to build a dam is considered, economic, social, and environmental impacts must be evaluated. Economic benefits can take many forms such as the development of agriculture or industry, or the creation of new communities. The basic characteristic of the subclass-dams is:

- The mass-balance equation: The operation of the reservoir behind the dam requires the knowledge of the reservoir storage. The estimation of reservoir storage at any time period (t) for all dams can be adequately obtained by using the mass-balance equation in its general form:

$$\text{Storage}_t = \text{Storage}_{t-1} + \text{Inflow}_t - \text{Release}_t - \text{Losses}_t \quad (1)$$

Attributes of a Dam:

- name-location,
- maximum allowable release,
- minimum required downstream release,
- electric power generation head difference requirements,
- spillway elevation,
- spillway capacity,
- discharge-elevation curve, and
- operation policies.

Subclass-Diversion Structures: The basic function of diversion structures is to raise the water level in a channel, so that water can be diverted without pumping. Barrages are defined as open type weirs or dams where water flows though the vents and does not spill over the crest. The vents reduce the chance of sedimentation upstream the barrages and scour downstream them, a common feature associated with the construction of weirs on alluvial channels. In addition, low head power generation plants may be installed. Another use for barrages can be short-term water storage.

The mass-balance equation for barrages has an extra term which represents water diversions:

$$\text{Storage}_t = \text{Storage}_{t-1} + \text{Inflow}_t - \text{Release}_t - \text{Losses}_t - \text{Diversions}_t \qquad (2)$$

Attributes of a Diversion Structure:

- name-location,
- intake levels,
- intake capacity,
- maximum water head difference between the upstream and the downstream, and
- maximum release.

Subclass-Locks: The function of locks in a surface water system is to facilitate navigation. Locks are types of structures that enable navigational units to pass through other control structures such as dams or barrages. They are also useful where a sudden change in water level occurs. The design of a lock depends on the type of navigational units to pass through as well as the traffic loads.

For the purpose of water resources management, locks are considered as a source of national income because they make navigation through regulated rivers possible. Transportation of goods and passengers using water streams is easy and inexpensive. Navigation through water ways is also used for tourism and recreation.

Attributes of a Lock:

- name-location,
- dimensions (length, width, depth), and
- transition time.

b) Groundwater: Groundwater is one of the most important fresh water sources. The amount of stored groundwater is huge. However, the cost of pumping groundwater varies greatly according to the water table depth under the ground surface. Figure 6 shows the hierarchical decomposition for groundwater.

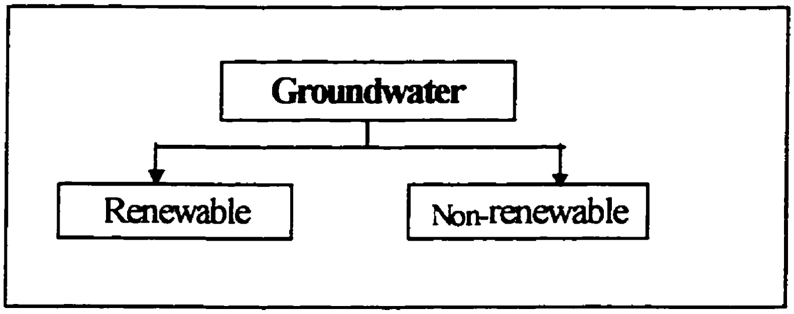


Figure 6: Groundwater Hierarchical Decomposition

b-1) Class-Renewable Aquifers: Renewable groundwater aquifers are those which have a replenishment source of fresh water. Renewable aquifers are recharged by seepage from local surface water streams, or from rain. Water withdrawal from a renewable aquifer must lie within the safe yield. The safe yield of an aquifer is the maximum water withdrawal that does not lower the water table in the aquifer. The safe yield depends on the ability of the aquifer to replenish (substitute) the water withdrawn from other sources.

Attributes of Renewable Aquifers

- water table level,
- characteristics of the water carrying layer (aquifer dimensions, soil type, etc.),
- safe yield (replenishment rate), and
- recharge sources.

b-2) Class-Non-renewable Aquifers: Non-renewable groundwater aquifers are those aquifers having no source for replenishment. Such aquifers vary in size and depth so that some of them can be used for much longer periods of time as long as the water use rate does not rapidly exploit the aquifer contents.

Attributes of Non-renewable Aquifers

- water table level,
- characteristics of the water carrying layer (aquifer dimensions, soil type, etc.), and
- aquifer water content.

c) Rainfall: Rainfall is the natural water recycling mechanism. Water evaporates from oceans, as well as fresh water lakes and streams, forming clouds that generate rain. Rainfall is measured by the depth of rain water accumulated during a specific period. The quantity of rain water varies greatly from one location to another. Factors affecting the quantity of rainfall in a region are:

- climatic conditions,
- topography, and
- geographic location.

Attributes of Class-Rain

- rain depth (quantity), and
- duration.

d) Drainage Reuse: Drainage water reuse is considered one of the non-conventional water resources. Recycling drainage water into the water resources system adds more available water to the system by using the same water more than one time. A problem that may be encountered in reusing drainage water is the level of pollution or salinity. For example, each crop has a maximum limitation for the salinity of irrigation water above which, the crop will not be able to use the water. Some other crops might have lower productivity due to the low quality of irrigation water. Treatment of drainage water before reusing it is one solution. Another solution for this problem is mixing the drainage water with fresh water to enhance the water quality up to the permissible limits.

Attributes of class-drainage reuse

- available drainage water quantity, and
- quality of drainage water.

e) Sewage Reuse: Unlike drainage water, sewage water cannot be used directly without treatment. The treatment process for sewage water varies from very preliminary treatment to remove harmful viruses and bacteria, to complicated processes to purify water from all pollutants.

Attributes of class-sewage reuse

- sewage water quantity,
- treatment facilities' capacity, and
- treatment level (recycled water quality).

f) Desalination: Although the quantity of water available for desalination is unlimited, the cost of the process is very high. A number of techniques are being developed in order to minimize the cost of sea water desalination. The capacity of sea water desalination plants depends, most importantly, on the economics of the project. Water produced using desalination is usually used for domestic or industrial purposes.

Attributes of class-desalination

- desalination plants capacity, and
- cost of desalination.

4.3.1.2 WATER DEMAND

The water demand class considers the integration of all water use sectors. Water uses can be classified into two basic types: consumptive and non-consumptive uses. Consumptive water uses apply to water which is used but only a portion of which is returned to the system. Non-consumptive uses require the availability of water in the stream while the same water can be used for other purposes. Water uses are:

- consumptive uses
  - agriculture,
  - domestic, and
  - industry.
- non-consumptive uses
  - navigation,
  - hydropower generation, and
  - environmental conservation.

a) Agricultural Water Use: The agriculture sector is the biggest water consumer. Increasing population and thus the need for increasing food supply put an even greater demand on this sector. In order to estimate the amount of water needed for the agriculture sector it is necessary to identify the types of irrigation methods used and the water requirements of the main crops under each method of use. Subclasses of the agriculture water use class can be represented either by sub-regions, by crops, or by irrigation method. In the case when the change in water consumption per crop is high depending on the location, it is better to sub-classify the agriculture sector into regions and to deal with each region separately. Figure 7 shows three types of hierarchical decomposition for the agriculture water use. The main attribute for this class is the equation of water requirement:

$$\text{Field Water Requirement} = \text{Crop Requirement} * \text{Irrigation Efficiency} \qquad (3)$$

The crop water requirement, called also *crop evapotranspiration*, is the amount of water to be consumed by the crop. This number depends on many factors such as crop type, soil type, and climatic conditions. The irrigation efficiency is the ratio of the amount of water the crop actually needs to the amount that should be given to the crop in order for it to be capable of extracting its needs. Irrigation efficiency depends on the method of irrigation and the soil type.

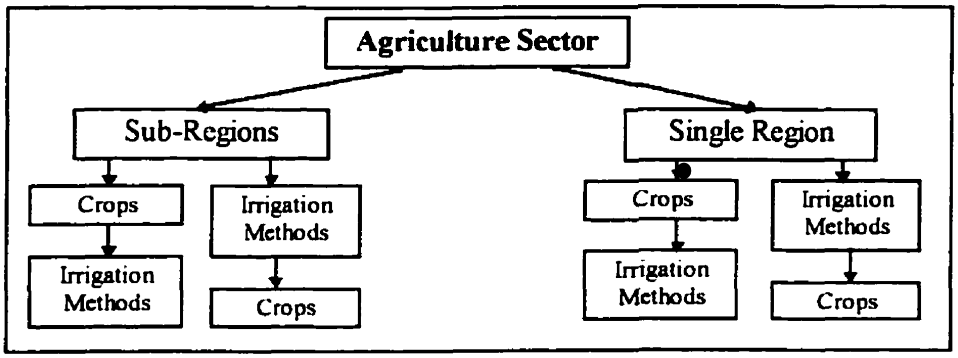


Figure 7: Hierarchical decomposition for agriculture water use.

a-1) Class-Irrigation Method: As mentioned above, the irrigation efficiency depends on the method of irrigation. Old agricultural techniques usually depend on submerging the field in water. These methods have very low irrigation efficiency, even lower than 50%. Modern irrigation techniques give more attention to reducing the amount of water given to the field by increasing the irrigation efficiency. For example, sprinkler irrigation can raise the efficiency to 75%, while drip irrigation can raise efficiency to more than 90%.

Choosing an irrigation method depends on many factors. The cost of installing an advanced irrigation system is much higher than traditional ones. However, when the water supply is insufficient or the cost of water is high, advanced systems may be preferred.

Attributes of irrigation method

- irrigation efficiency,
- capital and operation costs, and
- return flow quantity and quality.

a-2) Class-crop: Classification of crops in a region is a difficult process. The classification criteria differ greatly from one person to the other. For example, water resources planners classify crops according to water requirements, agronomists classify crops according to species, and agroeconomists classify crops according to the expected economic return or the economic importance.

Attributes of crop

- crop group name,
- cultivated area,
- water consumption (evapotranspiration),
- costs (seeds, employment, equipment, etc.),
- employment required (number of man-days),
- productivity, and
- economic return.

b) Domestic Water Use: Domestic water use is the amount of water required to be treated to satisfy specific needs such as (Khouzam, 1995):

- domestic use, e.g., in-house drinking, cooking, ablution, sanitation, etc.,
- industrial needs for treated water,
- commercial uses: shops, offices, restaurants, etc.,
- institutional uses: schools, hospitals, universities, government offices, and
- public uses: watering public gardens, sewer flushing, fire fighting.

Domestic water demand can be classified into two subclasses: urban and rural. Differences between these two subclasses arise from population density and the standard of living. Urban regions are more densely populated and the standard of living is higher than in rural areas resulting in an increase of the per-capita water requirements.

Attributes of class-domestic

- per-capita water requirements,
- population,
- percentage of population served,
- distribution network capacity,
- distribution network efficiency,
- cost of water treatment, and
- return flow (sewage system characteristics).

c) Industrial Water Use: Water is one of the main basis for development of the industry. Water is used in many processes in industry such as cooling and washing. Most of the water needed for industrial purposes is returned to the system. The hierarchical decomposition of the industrial water demand sector is shown in Figure 8.

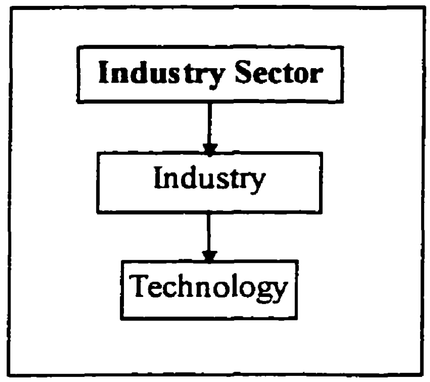


Figure 8: Industrial sector hierarchical decomposition

c-1) Class- Industry: The water demand for a specific type of industry depends on the water required to produce one unit of the final product. The range of variation of water demand for industrial use is great. Moreover, the quantity as well as quality of the return flow from each industry varies according to the use of water. When used for cooling, some water is lost due to evaporation while the quality is usually good. When used for washing, the water quantity consumed is much less but the water quality deteriorates.

Attributes of Industry

- industry type,
- production, and
- economic return.

c-1-1)Subclass-Technology: The rate of water use can also differ within the same industry type depending on the technology used. Technology, for example water recycling programs in industry, can affect the efficiency of water use.

Attributes of subclass-technology

- water requirement,
- water consumption rate, and
- return flow quantity and quality.

d) Navigation Water Use: Navigation is one of the non-consumptive uses of water. It requires a certain amount of water to be in the water stream in order to maintain a suitable water depth. Usually water released for other consumptive purposes is used for navigation. Two main subclasses can be identified within this class; recreation and transportation. The differences between these two subclasses come from the number of users for each type, which affects the quantity of water used, and the economic criteria.

Attributes of Navigation

- Number of ships,
- Minimum water depth requirement,
- Water requirement for consumption, and
- Economic return.

e) Power Generation Water Use: Power generation depends on the availability of water. This class can be divided into three subclasses: hydro, thermal, and nuclear power generation. The water use differs from one subclass to the other. Figure 9 shows the hierarchical decomposition for power generation water use class.

e-1) Class-Hydro: Electric power is generated when the water passes through the turbines of a hydropower generation facility usually installed in water control structures.

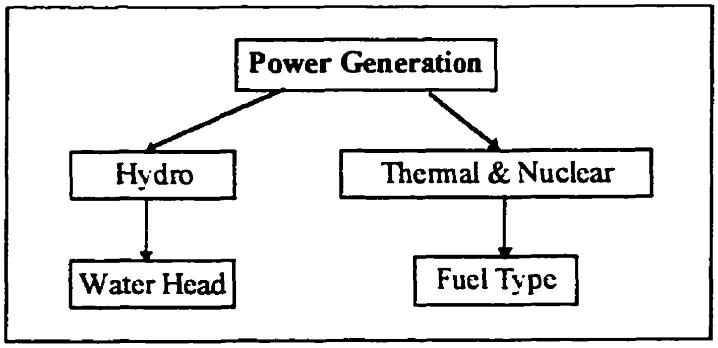


Figure 9: Power Generation Hierarchical Decomposition

Regardless of the capital costs of building a hydropower generation project, its operation cost is much less than other types of electric power generation as there is no fuel used.

Attributes of hydro

- turbines capacity,
- design water head,
- operation cost, and
- operation policy.

e-2) Class-Thermal & Nuclear: Although thermal power plants use other fuel such as charcoal and oil, water is needed for cooling purposes. Part of the water used for cooling evaporates due to high temperature, and the rest is usually conveyed into water channel which might cause some local effects on the environment.

Attributes of thermal & nuclear

- power production capacity,

- operation cost,
- water withdrawal, and
- water consumption rate.

4.3.2 Stage 2: System Dynamics

The dynamics of water resources systems consist of two main components: object states and links. The object state describes the possible variation in an object either internally or externally. Internal variation of an object is not dependent on any other object in the model while, external variation is caused by object interactions within the model. System links denote the physical as well as non-physical relationships among model objects.

4.3.2.1 Object States

Creation of a high quality model requires great attention in identifying all possible states that an object might take. Then, to eliminate some of the unnecessary complexities, the states that have relevancy to the model purpose must be selected. Table 1 illustrates the dynamics for important components of the system. The states column shows the attributes of the object that have a dynamic nature. The classification column indicates whether these states are affected by other objects based on the definitions mentioned in Chapter 3. The last column, Time step dependency, shows the effect of the model time step selection on the dynamic behavior of the objects. Some objects are sensitive to the time step so that they might have dynamic characteristics with shorter time steps and static characteristics with longer time steps. For example, crop water consumption can be considered a dynamic object if the time step is weekly or monthly. The same object is static if the time step is seasonal or yearly. It should also be noted that some of the classes are themselves objects as shown in the table.

The objects' states shown in Table 1 represent the driving factors for the model. The dynamic behavior of the model depends on the combination of initial as well as instantaneous states of objects.

4.3.2.2 Links

As mentioned previously, objects do not exist in isolation. Links among model objects mimic relationships in real life. The dynamic behavior of the model is generated through the interaction of model objects using the defined links. Links can represent physical and non-physical relationships. For example, water conveyance from one object to another requires a physical relationship. The effect of domestic water quantity on public health is an example of non-physical relationship. Table 2 and Figure 10 represent the most common physical links among objects of water resources models.

Table 1: Water Resources System Dynamic Objects

Super Class	Class	Object	States	Classification	Time step Dependency
WATER	Surface	River	• Water flow (Discharge)	• Agent	• Yes
			• Quality	• Agent	• No
RESOURCES	Water	Lake	• Storage	• Agent	• No
			• Elevation	• Agent	• No
			• Quality	• Agent	• No
		Dam	• Outflow	• Actor	• No
	Groundwater	Aquifer	• Water level	• Agent	• No
			• Storage	• Agent	• No
			• Quality	• Agent	• No
	Rain	Rain	• Quantity	• Actor	• Yes
	Drainage Reuse	Drainage Reuse	• Quantity	• Server	• No
			• Quality		

Super Class	Class	Object	States	Classification	Time step Dependency
	Sewage treatment	Sewage treatment	• Quantity • Treatment level	• Server • Actor	• No • No
	Desalination	Desalination	• Quantity	• Actor	• No
WATER USES	Agriculture	Irrigation	• Crop pattern • Crop water consumption • Irrigation efficiency	• Actor • Actor • Agent	• No • Yes • No
	Domestic	Domestic	• Population served • Per capita requirement • Network Efficiency	• Agent • Actor • Actor	• No • Yes • No
	Industry	Industry	• Production	• Actor	• Yes
	Navigation	Navigation	• Possibility (Availability of sufficient water depth.)	• Server	• Yes
	Hydropower generation	Hydropower generation	• Water head	• Server	• No

Table 2: Physical Links Among Objects of Water Resources Systems

Object	Object	Link
Surface water	Groundwater	• Natural or artificial aquifer recharge. • Conjunctive use. • Seepage.
	Rain	• Runoff accumulation
	Power generation	• Water head for turbines
	Navigation	• Sufficient water depth for navigation
Groundwater	Rain	• Recharge
Agriculture	Drainage reuse	• Agriculture drainage water
Industry	Drainage reuse	• Industrial waste water
Domestic	Sewage reuse	• Treatment sewage water
All resources	Water balance	• Accumulation of available water supply
Water Balance	All uses	• Distribution of available water to uses

4.3.3 STAGE 3: FUTURE FORECASTS

Water resources systems are dynamic in nature. Model dynamics require estimates concerning changes which may occur in the future. The amount of water available in the future depends on factors such as climatic changes and the current level of water consumption. Demand changes can be based upon specific targets for demographic or economic growth, or upon econometric analysis of future trends (Raskin, 1996). Two types of future scenarios can be used: the demand-driven or the supply-driven scenario (Simonovic et al., 1997).

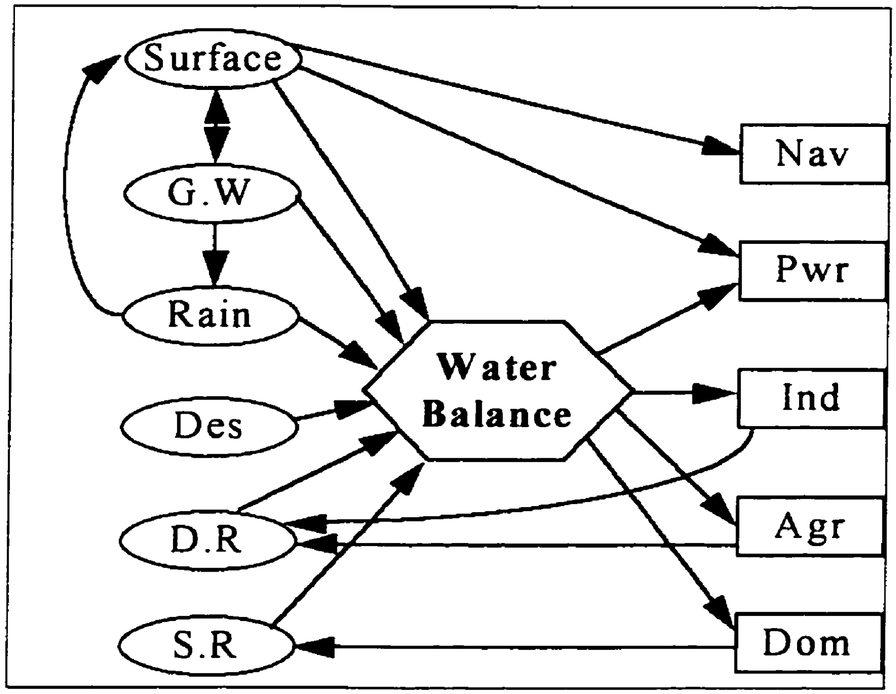


Figure 10: Water Resources System Links

4.3.3.1 Demand-Driven Scenario

Demand-driven scenarios assume the future levels of development for all demand sectors. For example, agriculture expansion plans can be translated into water requirements which add to the future water demand. Similarly, developments in industry or domestic water supply are also converted into water quantities to form the overall future water requirements. The sufficiency of the water supply is tested and in the case of a shortage, development plans to increase the supply should be studied and implemented.

4.3.3.2 Supply-Driven Scenarios

Supply-driven scenarios look at the current states of water sources, find the potential quantity of water to be used from every water source and all the limitations for attaining this potential value including economic and ecological criteria, and the time required for implementation of resources development. The quantity of water available is then allocated to meet projected demands. In the case where water resources exceed the demands, the excess water is allocated to an expandable sector such as agriculture.

4.3.3.3 Water Resources Forecasting

The amount of water available in the future should be based on the current status of the various types of water resources as well as on studies and analyses. These studies should be conducted for each individual resource as well as for the conjunctive use of all resources. The uncertainty as to the availability of most of the water resources adds complexity to the generation of water supply scenario. In order to overcome this problem, a set of scenarios including all the possible combinations of resources states must be prepared. Extra care must be given to this process in order to eliminate unexpected situations in the future.

Methods for estimating the future water supply vary. Simple methods using historical records or simple statistical estimations, as well as very complicated methods using statistical models to generate synthetic data such as multiple regression models or neural networks can both be used.

4.3.3.4 Water Demands Forecasting

Water demands depend on the level of development in the region under study. The higher the rate of development, the more water is needed to satisfy expansion requirements. Future forecasting for water demands is usually based on the independent development policies for each of the water demand sectors.

Methods of estimating water demands differ from one model to another. The main criteria for establishing accurate predictions of water demands are: i) the availability of past reliable data and ii) the stability of the region under study. These methods are based on the assumption that the possibility of having sudden or extreme changes in the future is not substantial. Some of the forecast methods for water demand are (USACE, 1994):

1. **Interpolation:** Demand values are specified for future years and demand values for intermediate years are computed by linear interpolation between the specified years.

2. **Growth Rate:** This method specifies a percentage for increasing the demand of the base year to be applied to future years. The water demand growth estimation using this method is non-linear.

3. **Drivers/Elasticities:** This method considers that the water demand is *driven* by other factors in the model. The elasticity is the effect of the driver on water demand. For example, domestic water demand depends on population. The driver in this case is the population and the elasticity is the rate of increase in domestic water according to an increase in population. In case of direct proportionality between the demand and the

driver, the elasticity value is 1.0. One water demand may have more than one driver with different elasticities.

4.3.4 STAGE 4: SYSTEM INDICATORS

Indicators are measures of conditions, processes, reactions or behaviors which provide reliable shorthand for complex systems. If relationships between indicators and the full sets of responses of such systems are known, the indicators can predict the status of the system. Where the relationships between components of a system and their symptomatic responses (indicators) are not well established, the status of the indicator is a poor predictor. This is the problem for indicators of sustainable water resources, particularly where the effects of human actions on the environment are being assessed. Measurements of some attributes of a system may show a change over time, but explaining the reasons for the change is often speculative. Quality indicators should have the following:

1. applicability, which relates to the suitability and the usefulness of an indicator,
2. significance, which refers to the meaningfulness of the indicator as a measure,
3. data quality, which examines the accessibility of data including the costs and difficulty involved in collecting data,
4. scientific validity, which means that indicators should be theoretically sound, dependable and credible, and

5. complexity, which means that indicators should be relatively easy to measure, predict, monitor and understand.

Indicators can be developed by combining model outputs to show the impact of development plans on each water sector (NWSRU, 1996). It is favorable to choose indicators which are global in nature to be used for comparisons with the present status as well as with international values such as levels of permitted concentration of pollutants in water. One of the basic indicators in water resources management is satisfaction of the water needs for all uses. It shows the adequacy of water supply development plans to meet total water requirements throughout the planning period. Tables 3 through 6 present the most effective indicators for the policies applied to the water resources system that can be combined in order to form meaningful indicators. (Source: NWSRU, 1994)

4.3.4.1 Environmental Indicators

Environmental indicators reflect the impact of water use on the state of the environment. For each of the water use sectors, the size of the pollution load conveyed to waterways can be calculated together with pollutant concentrations. Comparisons between different development plans can be made according to the pollution quantity or concentration.

4.3.4.2 Social Indicators

One important social indicator is the employment created in each water use sector. Job creation is a direct reflection of development in each sector. For example, land reclamation plans in agriculture create employment. The number of people who must be resettled to new areas can be used as a social indicator.

4.3.4.3 Economic Indicators

Economic indicators are used to show the effect of different development plans on the national economy. The value added to the GDP from each water use sector is the economic indicator that can be chosen to be modeled for agriculture and industry. The accumulated return from power-generation and domestic sub-models constitutes the added services value.

4.3.4.4 Political Indicators

Political indicators show the effect of the tested policy on some issues that might be considered of strategic political importance. Reducing the dependency on imports for some of the basic crops such as wheat or maize can be considered a political objective.

TABLE 3: ENVIRONMENTAL IMPACTS INDICATORS

Category	Environmental Impacts Indicators
1	Decrease in water quality (increased water salinity)
2	Soil degradation (increase in soil salinity)
3	Health hazard (air and land pollution)
4	Water logging (water table rise)
5	Total cultivated area
6	Crop yield
7	Aquifer depletion (long term impacts)
8	Soil erosion/sedimentation
9	Sea water intrusion
10	Groundwater pollution
11	Increase of aquatic weeds
12	Surface water savings
13	Effect on wild life population (vegetation, birds, trees,..)
14	Fresh water released to sea or stored in lakes
15	Drainage water released to sea
16	Effect on weather patterns
17	Effect on fish population

TABLE 4: SOCIAL IMPACTS INDICATORS

Category	Social Impacts Indicators
1	Farmers adaptability to new strategies
2	Effect on individuals' income
3	Land reclamation and expansion
4	Water users cooperation
5	Equity in water distribution
6	Considering farmer's ideas
7	Imposed prices by the government

TABLE 5: ECONOMICAL IMPACTS INDICATORS

Category	Economical Impacts Indicators
1	Economical analysis (national)
2	Financial analysis (individual)
3	Crop yield
4	Costs (investment, operation, and maintenance)
5	Water savings
6	Agricultural expansion
7	Equity (supply/demand)
8	Drainage water reuse (+ve) (saving water)
9	Drainage water reuse (-ve) (pumping costs)
10	Tourism (navigation), power generation, & fishing
11	Water pricing

TABLE 6: POLITICAL IMPACTS INDICATORS

Category	Political Impacts Indicators
1	Food self sufficiency and strategic crops import and export
2	Government internal policies (prices)
3	Water users associations involvement
4	Reclamation projects
5	Surface and groundwater use regulations
6	Surface water saving
7	Coordination between agricultural & irrigation policies
8	Impact on external policies (neighboring countries)

4.3.5 STAGE 5: PROBLEM IDENTIFICATION

Most water issues revolve around three factors: water quantity, water quality, and the establishment of priorities to deal with the limitations on quantity and quality. Regional and local agencies face increased frustrations as they attempt to plan for future community needs and try to implement their water supply, water quality, and wastewater management responsibilities. Environmental awareness and ecological system conservation add more complexity to the problem.

The process of problem identification requires great attention from system analysts as well as from decision-makers. Heuristic experience with the system under investigation must be employed to be aware of all possible problems which might occur when operating the system under different operation policies.

4.3.5.1 Types Of Water Resources System Problems

Water resources system problems on a regional policy level can be categorized into two groups. The first group is concerned with water quantity and the availability of sufficient water at the time of need. Poor management of the system can create water shortage problems even with adequate quantities. The second group focuses on the issues of water quality and environmental protection. This section discusses some of the most common water resources system problems.

a) Water Quantity Problems: Problems concerning water quantity are the most common problems in both developed and developing regions. Problems of water shortage may occur naturally due to changes in weather patterns or artificially because of increasing demands. Increasing pressure on available water resources from various competing users makes it more laborious to satisfy all needs of water supply for all users at the appropriate time. Water shortage may have several effects. It may affect the economy by limiting agricultural or industrial expansion, or it may cause social drawbacks such as increased unemployment rates or deteriorating public health. The ecosystem might also be affected by a water shortage which dries wet lands and endangers some species.

b) Water Quality Problems: The awareness of water quality problems is gaining more importance among water resources planners and decision-makers. Water quality problems come from the increased use of chemicals in agriculture, and the return flows from industries to water resources. Heavy water pollution may cause some sources to be hazardous to use. This affects the total water balance for the region. Categorization of water pollution problem depends on factors such as the types of pollutants emitted, pollutants concentrations, and disposal methods used.

4.3.6 STAGE 6: PROBLEM SOLVING MECHANISMS

Problem identification and solution require a collaborative effort between the system analysts and the decision makers. Involvement of decision-makers in this stage should be even greater. The previous stage has identified possible problems that might be encountered by the system in the future based on past experience. In this stage, possible solutions for identified problems should be found. Moreover, criteria for prioritizing one solution to the other must be cleared. Possible solutions for the previously identified types of problems, concerning water quantity and quality, are discussed in this section.

4.3.6.1 Water Quantity Problems

Water shortage problems are very common in both developed and developing regions. The methodology to be followed for solving such problem depends on many factors such as the availability of alternative resources, the availability of funding to support new water resources development projects, and other social and environmental factors. Some water resources development plans, such as the construction of dams, require relocation of people while other projects might have harmful effects on the ecosystem. In order to find an appropriate solution for a water shortage problem, planners must take into consideration all the consequences that follow the implementation of the selected solution. Figure 11 suggests a methodology to be followed in deciding on one solution, or a combination of solutions, to be taken and implemented into the system. This methodology assumes that the model is going to test the future effects of the solution on the system.

4.3.6.2 Water Quality Problems

Unlike water quantity problems, the variety of parameters of water quality that cause pollution problems is broad with different effects on humans and the environment. Another important aspect in water quality problems is that most pollution problems cause local effects which are not very well represented on the regional scale. Water quality problems usually happen due to lack of law enforcement regarding the use and disposal of hazardous materials in water ways or in groundwater aquifers. The solution in this case is to strengthen the authorities that enforce water quality regulations in order to prevent any hazardous waste disposal in water sources.

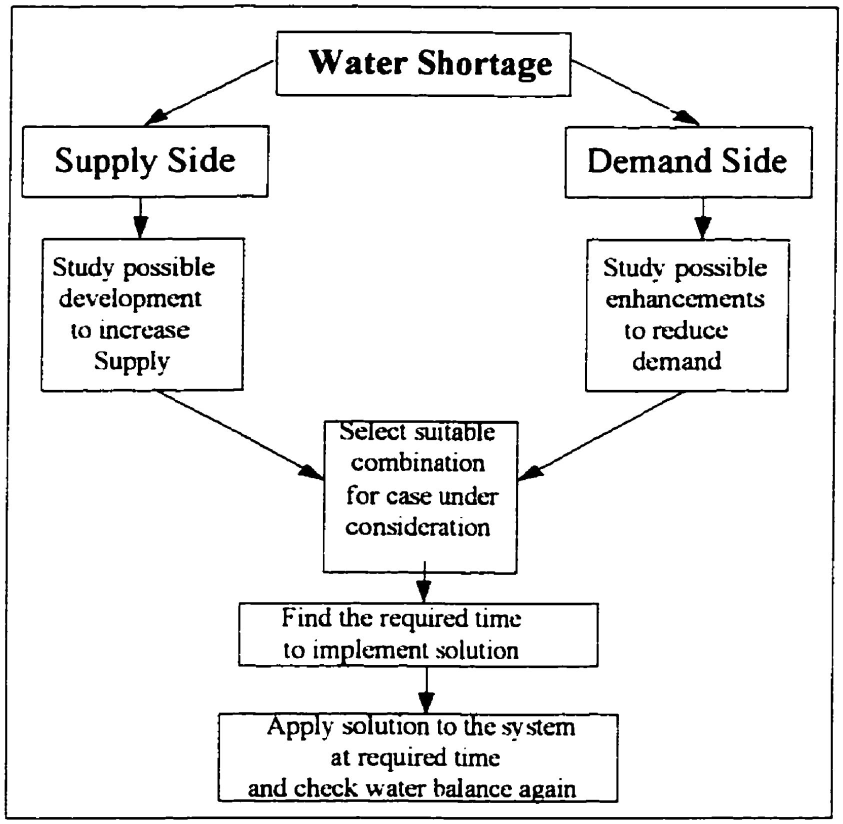


Figure 11: Water Shortage Solving Mechanism

4.3.7 STAGE 7: GENERAL MODEL DEVELOPMENT

The next stage in the framework is developing a water resources policy object-oriented model using the analysis done in the previous stages. The purpose of developing the model is to illustrate the applicability of the framework. The general model is a base model that can be used for any water resources system. The flexibility of the object-oriented modeling approach allows for quick modification of the base model for application on existing systems. Chapter 5 describes the process of general model development.

4.3.8 STAGE 8: CASE STUDY

Practical application of the general model is the final stage of the framework. Egypt's water resources system is chosen for the application. This choice is based on many factors. One factor is data availability. Another factor is that an object-oriented model, IWRMSD, has already been developed which makes the application easier by transferring some sub-models of IWRMSD to this application. Chapter 6 describes Egypt's water resources system, its problems, and the modifications applied to the general model. Results of the application for four different scenarios are presented and discussed.

CHAPTER 5

GENERAL MODEL DEVELOPMENT

5.1 INTRODUCTION

The objective of this chapter is to use the predefined framework from the previous chapter to build a water resources policy model. The function of the model is presently limited to testing the effect of various strategic water policies on the water balance. The policy variables of the model are divided into two groups. The first group includes the development of economic sectors such as agriculture, industry, and services. Development in these sectors is translated into water requirements which are added together to form the overall water demand for the region. The second group of policy variables includes the development required in the area of water resources to accommodate all current and future requirements. For illustration purposes, the application of the framework stages is implemented through development of a general water resources system model with two resources and two demands. The description emphasizes the application of the methodology using the selected object-oriented modeling environment, STELLA II, and the modifications necessary to adapt this methodology to fit STELLA II's limitations.

5.2 MODEL DEVELOPMENT

5.2.1 MODEL COMPONENTS

Following the framework, the model consists of four basic components; water sources, water demands, water balance, and time control.

5.2.1.1 Water Sources

Water sources in this model consist mainly of two sources. The first source is an infinite resource that has an unlimited capacity. This source can represent a rechargeable groundwater aquifer and its capacity is the safe yield beyond which the water level in the aquifer will be endangered. The second source is time dependent i.e. its value changes according to the time change. There are many examples of such source, some of which include natural, uncontrolled, rivers, or rainfall. It's assumed that both sources are not yet fully utilized. The model allows the flexibility of adding to each source with the limitation of its own potential value.

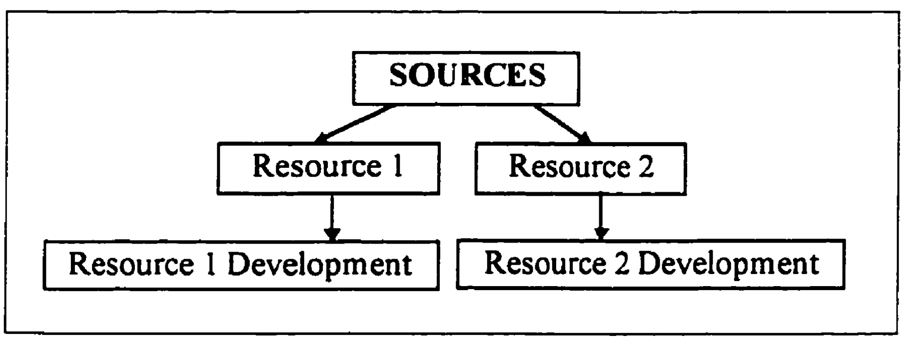


Figure 12: General Model Water Sources

5.2.1.2 Water Demands

Two different water demands are identified. Both demands are considered dynamic as functions of time. This assumption allows for future developments such as agriculture expansion, industrial development, or drinking water supply enlargement. For each of the demand sectors, the model also allows for cutbacks in the demand as a percentage of the demand. The cutback is considered one of the decisions to be taken in order to overcome a water shortage problem.

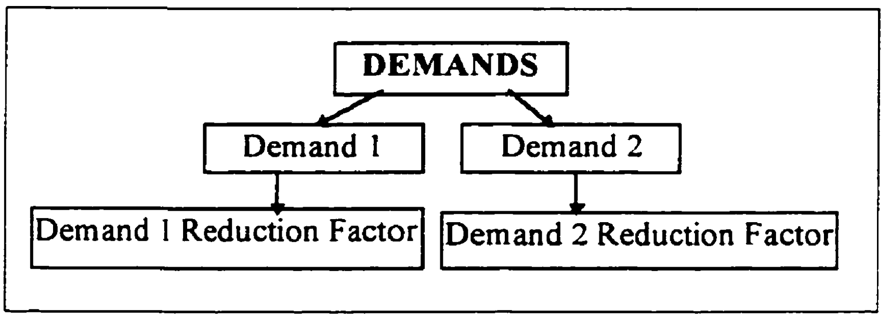


Figure 13: General Model Water Demands

5.2.1.3 Water Balance

The water balance component is concerned with the augmentation of the water resources system in order to form the final conclusion about the system's status. This component's function is to check the availability of water to satisfy all demands. At this point, the decision about proceeding to the next time step or backtracking to try to find a suitable solution is made. The water balance component contains the time control unit. The time control unit is responsible for the regulation of the model's time frames. Based on the decision made by the water balance component, messages are sent to this unit to

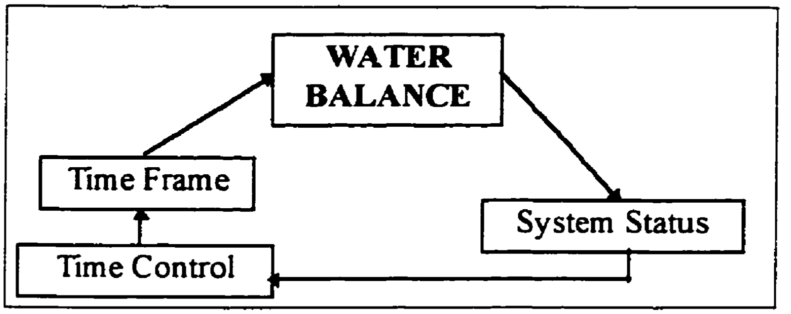


Figure 14: General Model Water Balance

either proceed to the next time frame or to send a message to the development plans component to make the necessary adjustments to the operation policies.

5.2.1.4 Development Plans

This component is responsible for finding suitable solutions to water shortage problems. Messages are relayed from the water balance component to indicate the existence of a problem. Two techniques which are used for the development of this component will be discussed later in the system dynamics section.

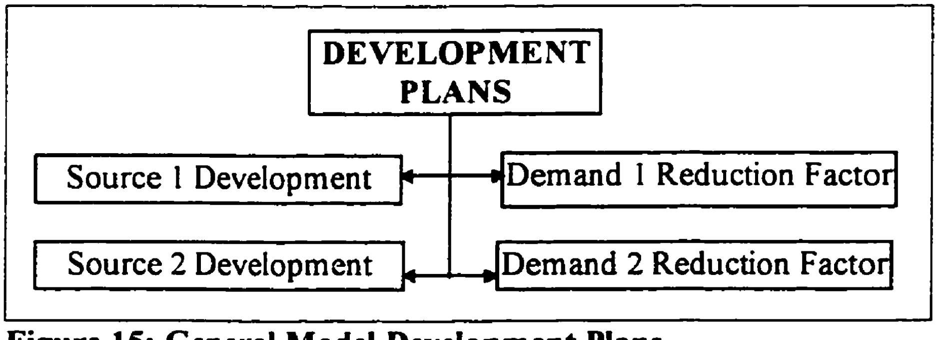


Figure 15: General Model Development Plans

5.2.2 SYSTEM DYNAMICS

The system dynamics step is concerned with the identification of the states of each object in the model and the discovery of the interrelationships that connect the model objects together to simulate the real world. The level of complexity used in achieving this step is highly dependent upon the available sources of data, the modeling time limitations, and the required level of complexity and accuracy of the model. Table 1 shown in stage 2 in the modeling framework depicts most of the commonly used objects along with their possible states. For this application, a limited number of objects will be considered. Table 2 in the same section identifies all possible connections among objects. Table 7 shows the classification and states of the model objects along with the interdependency among them. Figure 16 shows links among the four basic sectors of the model.

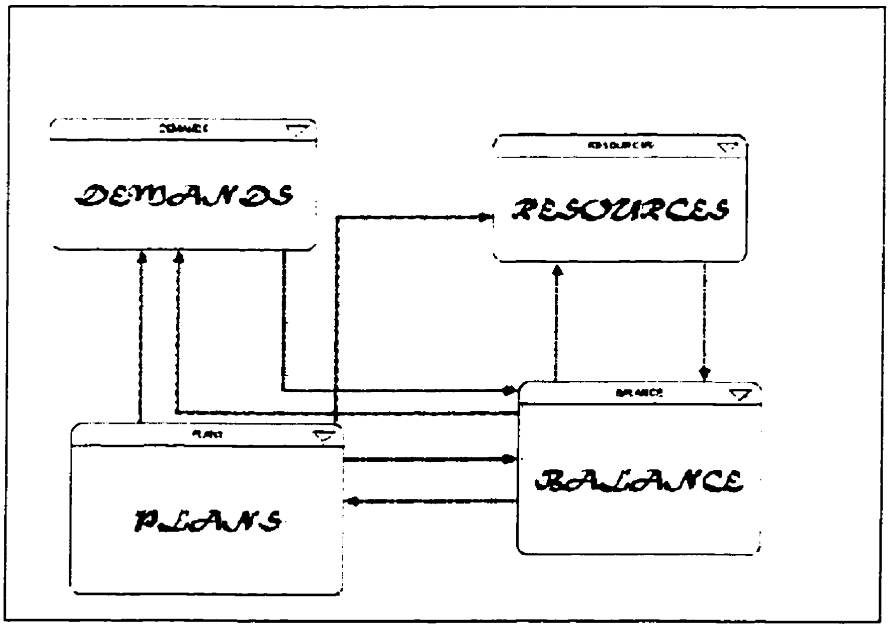


Figure 16: System Links

Table 7: Dynamic Characteristics of the Model

Object	Classification	States	Actors
Source 1	Actor	Water Quantity	N/A
Source 2	Actor	Water Quantity	N/A
Sources	Agent	Water Quantity	Source 1 Source 2
Demand 1	Actor	Water Quantity	N/A
Demand 2	Actor	Water Quantity	N/A
Demands	Agent	Water Quantity	Demand 1 Demand 2
Water Balance	Agent	Water Quantity	Sources Demands
Time Step	Agent	Time	System Status
Time Control	Agent	Time	Development Plans
System Status	Agent	Satisfied Not Satisfied	Water Balance
Development Plans	Agent	Selected Plan	System Status
Source 1 Development	Agent	Yes / No	Development Plans
Source 2 Development	Agent	Yes / No	Development Plans
Demand 1 Reduction Factor	Agent	Yes / No	Development Plans
Demand 2 Reduction Factor	Agent	Yes / No	Development Plans

5.2.3 FUTURE FORECAST

Possible future scenarios for both resources and demands components are considered among the model inputs as decision variables. For water resources, future utilization of each resource is dependent on the decisions to be taken by the development plans sector. Limitations for future use of resources depend on the studies that estimate the current and potential amount of water to be consumed from each resource. Water demands should be considered as input data to the model. The numbers can be estimated using any of the methods such as extrapolation or growth rates mentioned in Chapter 4. Water demands can also be estimated using data from other specialized models and connected to the model.

5.2.4 SYSTEM INDICATORS

Because this is a general and basic model, the only indicator included is the water balance indicator which shows the adequacy of water to meet all demands. In applying this general model to real world problems, more indicators may be incorporated into the model. The selection of indicators is highly dependent on the study case. Furthermore, data availability plays a great role in determining the indicators to be used.

5.2.5 PROBLEM IDENTIFICATION

The major and most common problem in water resources system management is water shortage. Hence, this model considers this problem to be the core of the model. Other problems such as water quality degradation, salt water intrusion, or water logging can be dealt with in applications as well.

5.2.6 PROBLEM SOLVING MECHANISM

The main concept of this procedure is to identify the existence of a problem and try to solve, or help the decision maker solve it. The implementation of this step is achieved by two different feedback mechanisms. The first mechanism is manual feedback using an interactive method that allows the decision maker to implement his or her own ideas. The model stops as soon as it encounters a problem, prompts the user that some problems have occurred in the system, and waits for the user's response and decision in solving the problem. The simulation then continues until encountering either other problems or until the end of the simulation period.

The second feedback mechanism is an automatic method that depends on a set of alternatives that are ready to be implemented whenever a problem is encountered. Some preparatory steps must be taken into account before using the model. The first step is the identification of all possible solutions to the problems and the ranking of them in order of priority. Priorities can be ranked according to many economic, social, environmental, and political factors.

5.2.7 General Model Implementation

The four main components mentioned above namely, water resources, demands, balance, and development plans are represented as sectors in STELLA II object-oriented modeling environment. A sector is a group of objects that forms a larger component to achieve a specific task in the model. Classification of the model tasks using sectors allows elaboration on every task independently with minor considerations for other model tasks. Figures 17 through 20 show the implementation of the model in STELLA II. The program equation listing and details of each of the model objects can be found in Appendix 1.

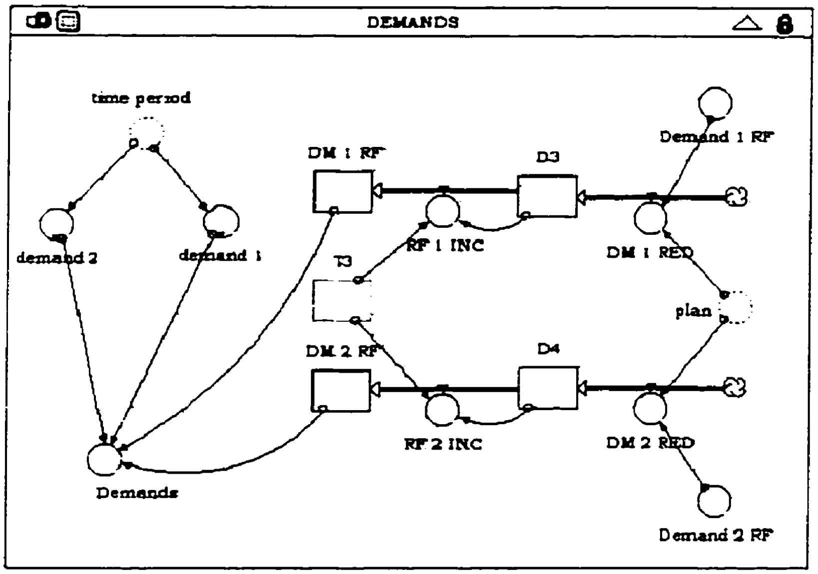


Figure 17: Water Demands Sector

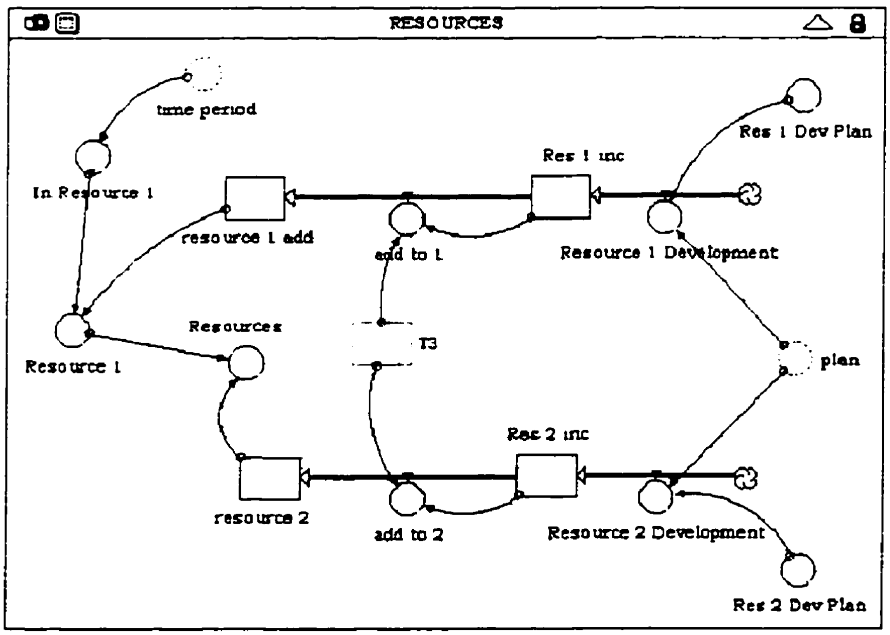


Figure 18: Water Resources Sector

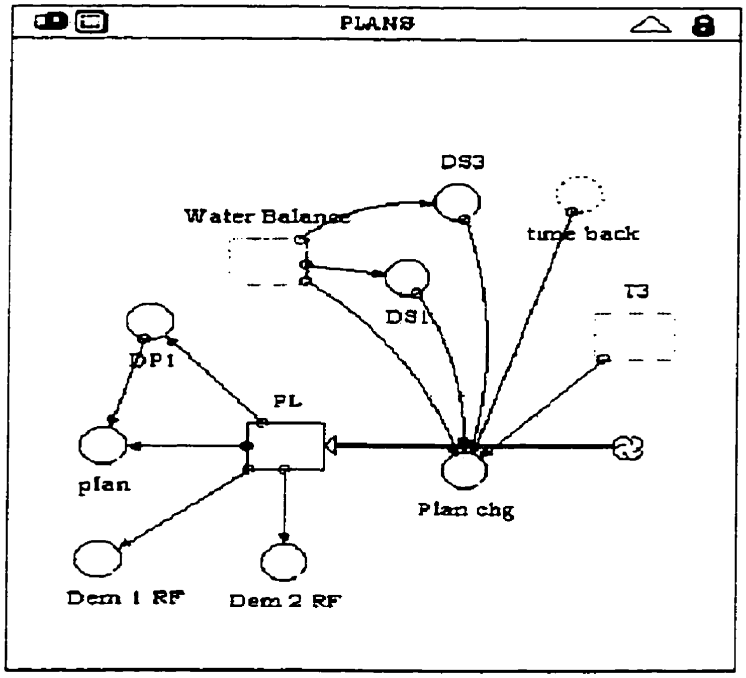


Figure 19: Development Plans Sector

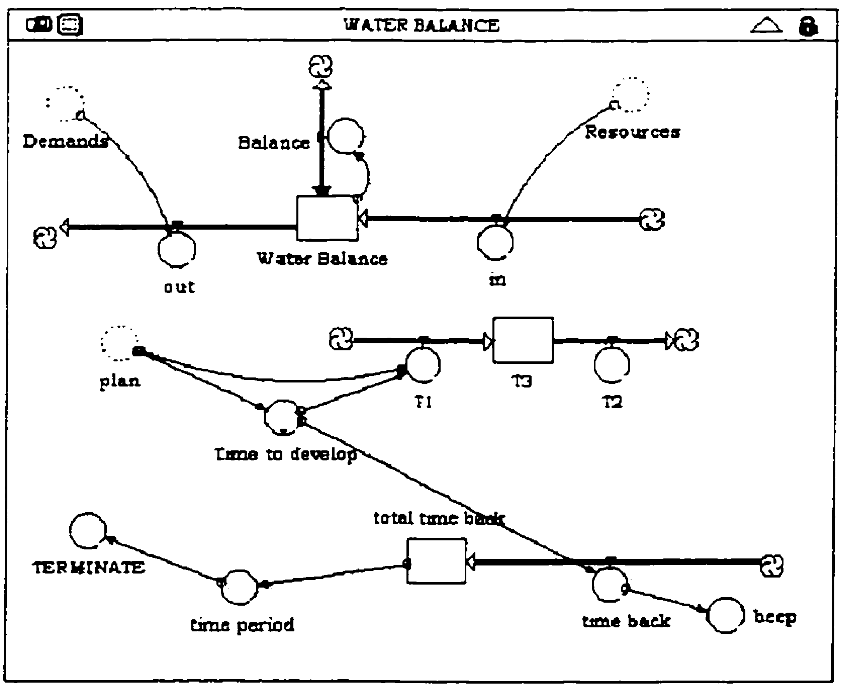


Figure 20: Water Balance Sector

The four sectors shown in Figures 17 to 20 represent the components of the general model. The resources sector is responsible for delivering the water into the system, and the demands sector is responsible for estimating water requirements for the system. The overall water balance is checked in the water balance sector. The decision to be taken in each time step originates from the information obtained from the water balance sector as a result of the water balance. In the case of a positive water balance the decision is to proceed to next time step. In the case of a negative water balance the decision is to consult the development plans sector for alternatives. The development plans sector has predefined alternatives to be implemented in the case of a water shortage. This sector can either command the water resources sector to develop one of its water sources, or ask the water demands sector to reduce the requirements. The ranking of alternatives is dependent on the decision-maker's preference and is considered outside of the scope of this research. For each of the decisions taken in the development plans sector, the time required for implementation is taken into consideration by the "time back" object that causes the model to go back in time and start implementing the development plan at a suitable time so that the water shortage problem is eliminated.

5.2.8 COMMENTS ON IMPLEMENTATION

- Some objects are shown in dotted lines on the map. These objects originate in one sector and are used in other sectors. The dotted object represents a link between two sectors. All sectors links are presented in Figure 16.

- In order to correctly represent the water resources system using STELLA II modeling environment, additional objects had to be used. As the types of objects in STELLA II are limited, some combinations of objects are used. For example, in order to implement the resource development plan, the structure given in Figure 18 takes the decision from the "plan" that originates from the development plans sector and takes the amount of water to be added to the water sources from "Res 1 Dev Plan". The gradual increase in the water quantity supplied by this source is achieved using the stock-flow structure shown in Figure 18 which finally adds water to "resource 1" object.

- The main time control object in the model, Time Period, is responsible for the identification of the time frame that the model uses for resources and demands. The development plans time control object, T3, is the one responsible for the adjustments in time required for the implementation of development plans and affects only the periods of time that require implementation of resource improvement or demand management plans. The overall model time frame control is the "Time Period" object. It should be noted that STELLA II has its own time control system that only proceeds in a forward direction. Using the set of time control objects is necessary in order to implement the feedback process that takes results from the water balance and sends the model back in time to start implementing the alternatives before the estimated year of shortage.

- The model assumes gradual implementation of development plans. The total outcome of each plan is divided equally into the number of time frames required to implement the plan. This assumption sounds reasonable especially in the area of demand management as well as for most resources development programs such as groundwater or water reuse.

5.2.9 MODEL USER INTERFACE

One of the advantages of STELLA II is its ability to design an interactive user interface without expending an excessive amount of time and effort. The environment allows the designer to custom-build a user interface that satisfies the user's needs with the ability to be changed according to the needs.

The model user interface is divided into three main areas. The first area enables the user to change the values of the decision variables in the model. The second area displays messages generated from the model which inform the user of the system status. Finally, the third area displays graphical output that shows the dynamic changes in the system's status over time and provides a wide range of model's objects selections to be displayed on the screen while the simulation is running. Figure 21 shows the general model user interface.

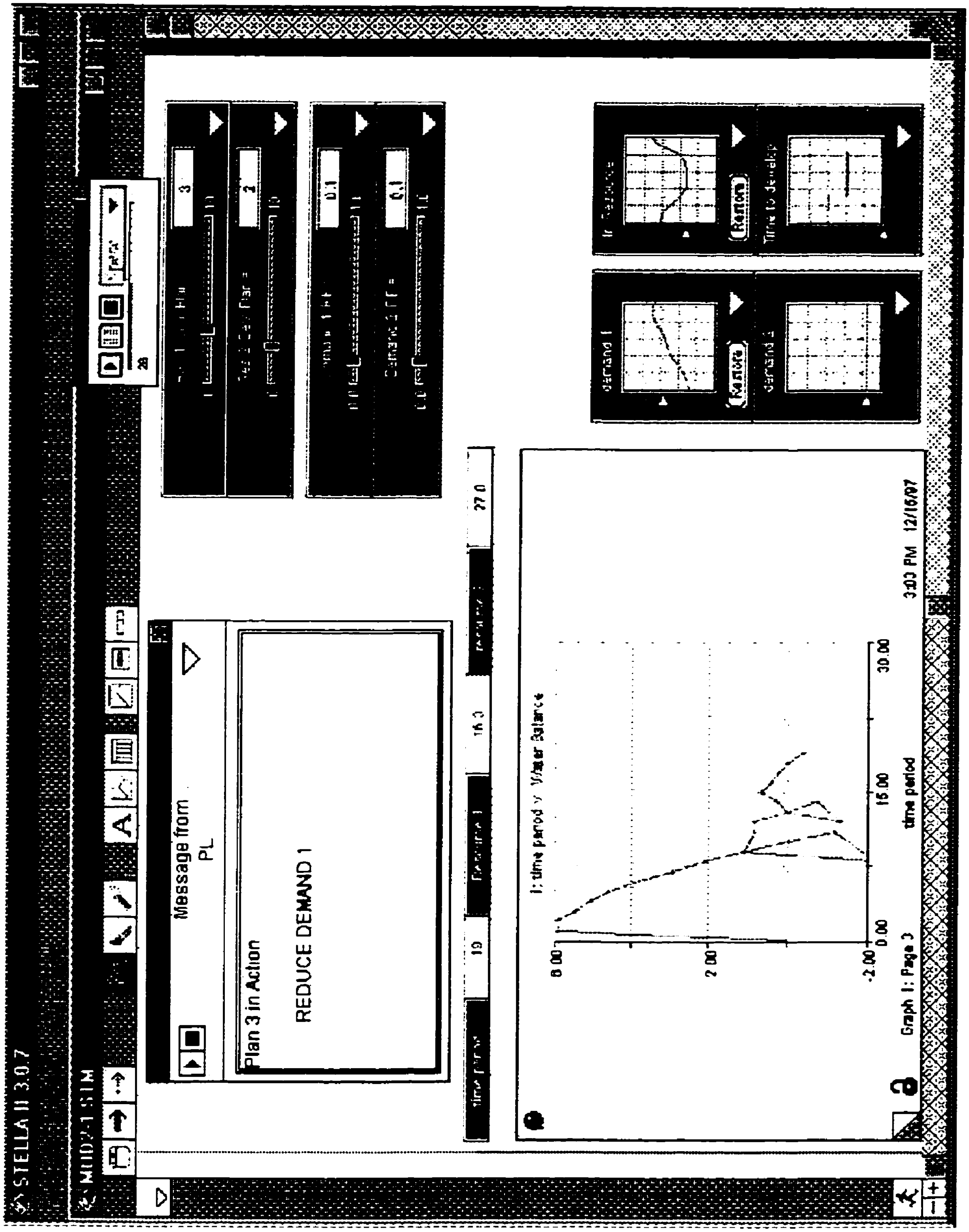


Figure 21: General Model Graphical User Interface

CHAPTER 6

CASE STUDY

6.1 INTRODUCTION

The objective of this chapter is to demonstrate the capabilities of the object-oriented programming technique by applying the general model developed in the previous chapter to a real water resources system. The application is intended to illustrate the advantages of using object-oriented programming over traditional languages. The regional water resources system selected for the application is Egypt's water resources system. This system was chosen mainly because of the data availability and the presence of previous trials to simulate the system. In this chapter, the water resources system in Egypt is briefly presented along with the risks that face its management, modifications applied to the general model are described, some scenarios for operation are tested, and results of simulations are presented and discussed.

6.2 SYSTEM DESCRIPTION

6.2.1 GENERAL

Egypt covers an area of approximately 1 million sq. km. (386,662 sq. mi.) in northeastern Africa. Its northern coastline along the Mediterranean Sea and its eastern coastline is the Red Sea, touching the State of Israel in the Sinai. Libya shares its western border, and Sudan its southern border. Egypt is overwhelmingly a desert country bisected by the River Nile. Over 90% of the land area is formed by a convergence of deserts. There are oases scattered across this wasteland as well as a swathe of land along the Suez Canal which is cultivated, but it is mainly the land fed by the River that is both habitable and arable. The Sinai Peninsula is formed of sand desert and spectacular mountains rising as high as 2,637m (8,652 ft) above Red Sea level. The capital city is Cairo located on the Nile Delta apex.

The population of Egypt stands at around 62,000,000, with projections placing the population at 65 million by the end of 1998. Although the birth rate has decreased slightly (from 2.8% annually in the 1980s to 2.3%), ongoing population growth is Egypt's greatest and most intractable problem, exacerbated by the sheer lack of habitable land area. Almost the entire population lives in the Delta and in the Nile Valley which is only about 4% of the country's land area, making this land one of the most densely populated areas in the world.

6.2.2 WATER RESOURCES OF EGYPT

Egypt's water is mainly derived from the River Nile and from a limited fossil groundwater. In the future, other sources such as desalinized sea water, harvested runoff from the scarce rainfall on the northern sea coast or Sinai, and the water saved by the Upper Nile conservation projects may be added to the system. Table 8 shows the available resources as they are currently used along with their potential values. It should be noted that supply sources are listed in an ascending order based on the associated costs of each resource.

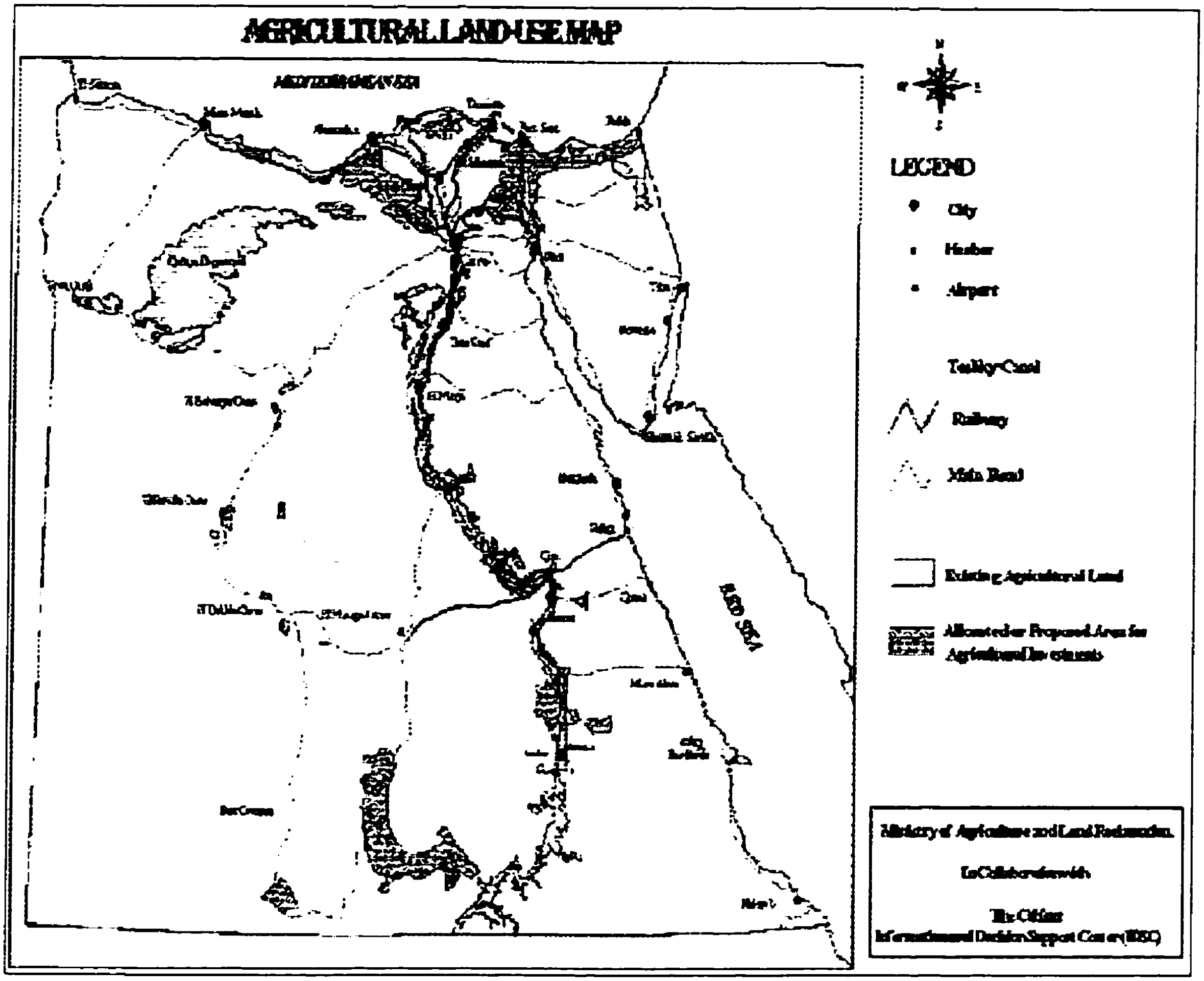


Figure 22: Agricultural Map of Egypt

Table 8- Current and Potential Values for Water Resources in BCM* (billion cubic meters)

Resource	Current	Potential
River Nile	55.5	58
Shallow Groundwater	2.5	4.5
Deep Groundwater	0.5	3.1
Drainage Reuse	4.7	7.1
Sewage Reuse	0.1	2.0
Desalinization	0	Unlimited

Some water uses are consumptive while others are not. The consumptive uses are agriculture, domestic, and industry. Although navigation is usually a non-consumptive use, it requires maintaining a sufficient water depth in the river which leads to about 1.8 billion cubic meters per year being lost to the sea. Current studies are underway to make use of this amount and to study its effect on coastal encroachment. Non-consumptive uses are limited at the present time to power generation. Environmental public awareness may add, in the future, to the traditional water demands. Table 9 shows water demands for each sector for years 1990, 2000, as well as three scenarios for the expected demands for the year 2025. Scenario A represents the most optimistic case, B represents the most likely case, and C represents the most pessimistic case. It should be noted that all scenarios assume that the irrigation efficiency will increase in the future causing the agriculture water demand to decrease.

Table 9- Current and Future Main Water Demands in BCM

Water Use	***1990***	***2000***	***2025***		
			A	**B**	**C**
Agriculture	50	60	44	47	50
Industrial	4.1	6.1	9.6	11	15
Domestic & Municipal	3.1	3.1			
Navigation	1.8	0.3	0.3	0.3	0.3

Due to the low efficiency of irrigation practices and seepage losses, a large amount of water supplied for irrigation either goes to the drainage system or becomes stored in the shallow aquifers in the Nile Delta and Valley. The Ministry of Public Works and Water Resources (MPWWR) has started programs to recycle drainage water and to use shallow groundwater to increase overall system efficiency. At present, it is MPWWR's policy to expand already existing reuse programs and to initiate new ones such as the reuse of treated waste water.

6.3 WATER POLICY PROBLEM DEFINITION

There have been great efforts to study in detail and understand most of the elements of the water system. Still, there have been shortcomings in the aggregate-level studies that adopt a long term global integrated approach in water resources planning and management. One shortcoming is the failure to recognize the interrelationships among different sources of water supply, and the failure to incorporate these interrelationships into future-looking analyses. The potential of some supplies is highly dependent on other supplies. For example, shallow groundwater, which is considered a water supply source, is usually recharged by both river water and agricultural drainage. Thus, the actual total potential of water is not equal to the sum of potentials listed in Table 8. The actual value of total potential water supply is less than the sum. Simulation models are needed to recognize and incorporate these interrelationships among supply sources.

The second shortcoming is that water policies in the past have failed to look at the demand-supply system in a sufficiently iterative manner. Past policies have simply considered a fairly large time horizon (e.g. 10 or 25 years into the future), projected what water demands will be at the end of that period, and then tried to plan for a supply to meet that demand. These policies have failed to incorporate a more iterative approach that looks at supplies and demands more frequently over time, thus allowing for dynamic adjustments that could significantly affect supply and demand figures in the longer term. In addition to the fact that numbers used were uncertain, no scenarios were generated on the two sides of the supply-demand equation. The dynamics and uncertainty in each element of the demand-supply equation make the decision maker very reluctant to adopt such policies

To draft a water policy that can account for the uncertainty in the future demand-supply equation, different scenarios should be generated for demand and supply on an aggregate level throughout the planning horizon. The scenarios have to couple the development plans and growth of all the demand sectors with potential development of water supply sources. They must also reflect the interrelationship among various supply sources. For each scenario, alternative solutions for supply-demand matching problems should be derived. To develop a complete comprehensive water management strategy, the environmental, economical, and socio-political impacts of the alternative solutions have to be evaluated for each scenario. A water management strategy in this sense will provide the decision makers with a full decision tree that has many alternatives from which they can choose.

The IWRMSD model, explained in detail in Chapter 2, was designed to tackle some of the above mentioned problems. The approach used in developing this model incorporates sustainable development criteria in water resources management in Egypt. The model represents the future of water resources system in Egypt as a function of economic development and gives a wide range of social, environmental, and economic indicators. A detailed discussion about the IWRMSD and the work done through this thesis is also given in Chapter 2.

6.4 MODEL APPLICATION

6.4.1 MODELING ASSUMPTIONS

6.4.1.1 Water Sources

Since the River Nile is the main source of water for Egypt, the application assumed that the River Nile is the only source to be presented in detail. Other water sources such as groundwater, rain, drainage reuse, and desalination are aggregated in one object given a value equal to the sum of these sources. Natural river inflows are taken from historical records for the River Nile at Aswan upstream the High Aswan Dam (HAD). The water storage in the HAD reservoir is simulated considering different losses such as evaporation and seepage. Limitations regarding water released from the dam are taken from previous reports about the HAD reservoir model such as WMP (1981).

6.4.1.2 Water Demands

As shown in Table 9, agriculture is the major water use sector in Egypt. Agriculture consumes more than 84% of the total water demand. Therefore, agricultural water demand is given higher emphasis in the model. The agriculture sector is divided into two main regions; old land and new land. Cropping patterns for the old land consists of the most common ten crops, while new land cropping patterns consists of five main crops. For each of the crops, the water requirements, costs of cultivation, and average benefits per unit area are included in the model. Other water demands are summed into one object and given a time dependent function. The values of other water demands are interpolated from future forecasts.

6.4.2 MODIFICATIONS TO THE GENERAL MODEL

6.4.2.1 Water Resources

The water resources sector in the application uses the same number of resources available in the general model. However, the River Nile as the main water source is modeled into a separate sector so that some details of the river's status could be introduced. The main control unit on the river is the High Aswan Dam (HAD). The lake of the dam has a maximum capacity of about 163 billion cubic meters. The HAD sector is capable of simulating the variations in the lake storage and controlling the dam releases in the case of a critical storage stage. The model used to simulate the reservoir is taken from a previous model in Fahmy and Aboelata (1995). The original lake simulation model has been slightly modified to fit into the application and to connect it to the resources sector. Figure 23 shows the High Aswan Dam Sector in the application.

6.4.2.2 Water Demands

The water demands sector in the application has two sources of water demands. The first and most important source is agriculture. The agriculture sector is the major water consumer in the system. Due to the dry climatic conditions which prevail in the region, agriculture depends mostly on irrigation. The irrigation network was initiated quite a long time ago. Nowadays, the network is very complicated. Other water demands such as domestic, industry, navigation, and power generation are summed together in one object called 'other demands.'

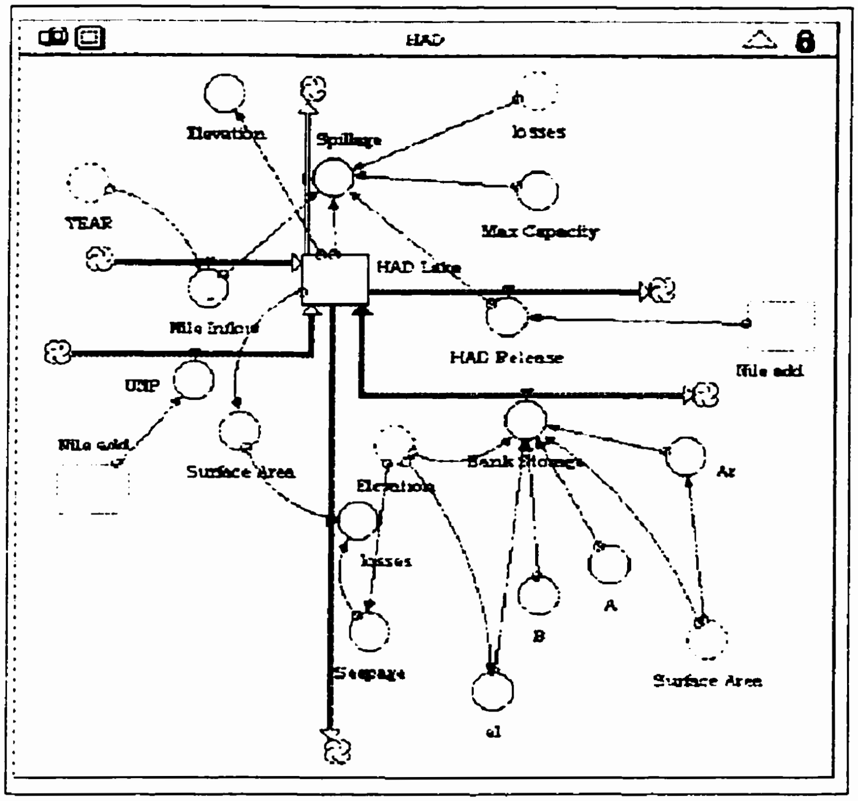


Figure 23: High Aswan Dam Sector

The flexibility obtained by using object-oriented programming makes it possible to reuse already existing models when building new ones. The agriculture sector was neatly introduced in the IWRMSD model. Hence, the same sector has been copied in this application. The total agriculture requirements are divided into two major units; old land and new land. This separation is necessary in order to differentiate between the efficiency of the types of irrigation used in each unit. Old land agriculture areas use flood irrigation which require large amount of water while new land agriculture areas use modern, more efficient irrigation techniques such as drip or sprinkle irrigation. For the old land, the crops are divided into ten major groups that can effectively represent the cropping patterns in the region. The area to be cultivated by each crop is among the decision variables of the model. Similarly for the new land, five major groups of crops are present. The decision variable concerning new land is the land reclamation plan to be implemented over the planning period. In this sector the total water requirement for both divisions is calculated according to the specified irrigation efficiency for each.

The agriculture sector in IWRMSD considers other values such as the fertilizers and pesticides used in agriculture to be calculated and are linked to the drainage water quality to be included among environmental indicators. Unfortunately, not enough data were collected about either the use of fertilizers and pesticides or their effect on the drainage water quality. Therefore, the objects concerning these calculations have been eliminated from the agriculture sector in the application. Figure 24 shows the first five groups of agriculture crops along with the associated parameters to be calculated such as

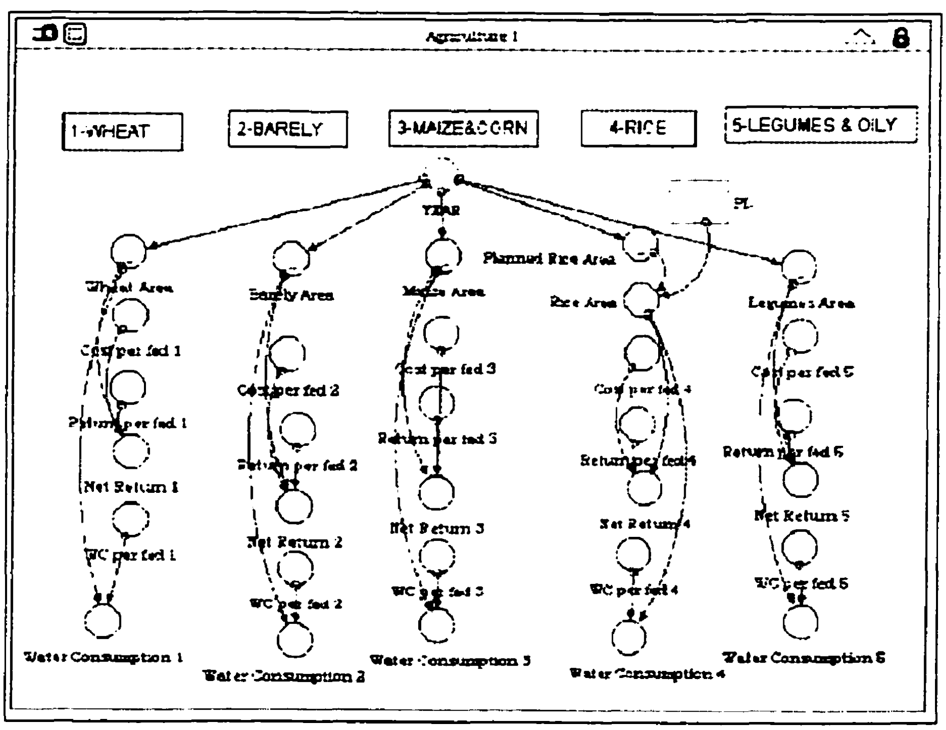


Figure 24: Agriculture Sector

the total water requirements for each crop, costs, and expected benefits. It should be noted that the only crop that is exposed to modifications in its cultivated area is rice as it has the highest water requirements among all crops. Figure 25 shows the new land sector in the model. Calculations originate from the planned increase in new land and proceed similar fashion to that of the old land. The total water required for agriculture consists of two components. The first sums up all the water requirements for old land crops after adding the effect of irrigation efficiency. Similarly, the second component adds up the water requirements for new land crops while taking into account the irrigation efficiency.

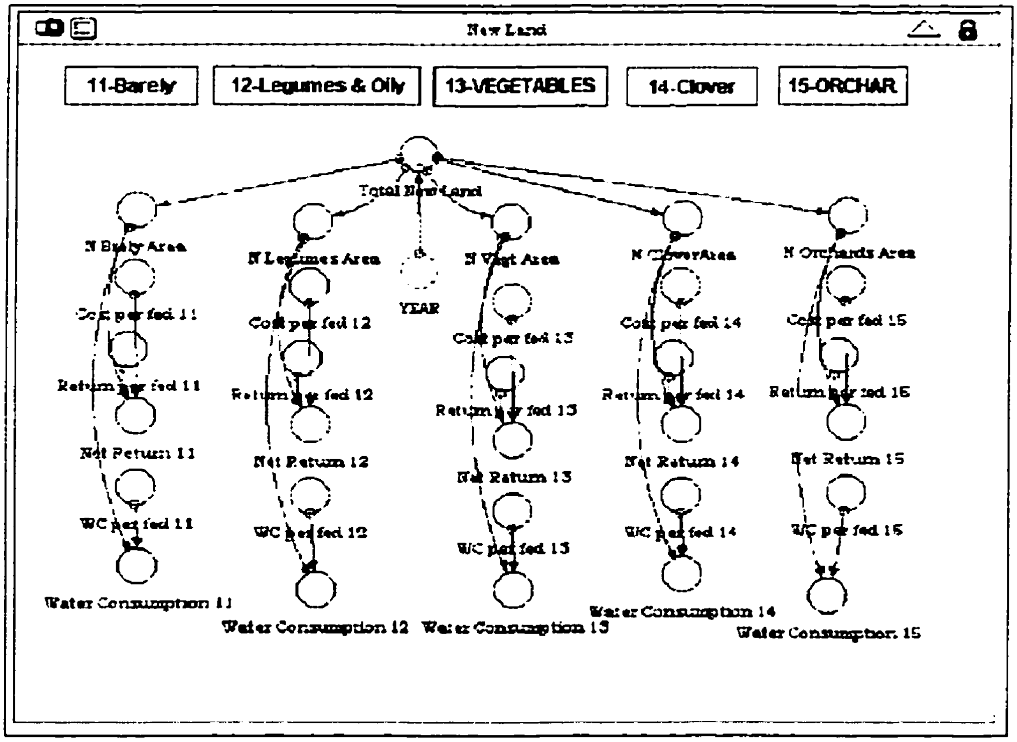


Figure 25: New Land Sector

6.4.3 GRAPHICAL USER INTERFACE

The graphical user interface is designed to give most of the necessary information about the system on one screen. Figure 26 shows the appearance of this screen during the simulation process. The upper left corner displays messages from the model to the user to indicate that the water resources system has encountered a problem. It also displays the resource development plan to be implemented to overcome the problem. The screen shows a graphical representation for the water balance simulation over time. As shown on the graph, the simulation process stops at the 27^{th} year and displays the message indicating that there is a need to develop groundwater. A numerical display for the exact value of the water balance at this point is also available above the graph.

Decision variables in the model are shown on the right side of the screen. The upper part shows the values chosen for resources development plans and gives the user the capability to change them. The lower part is used to display the economic development plans, scenarios, to be tested.

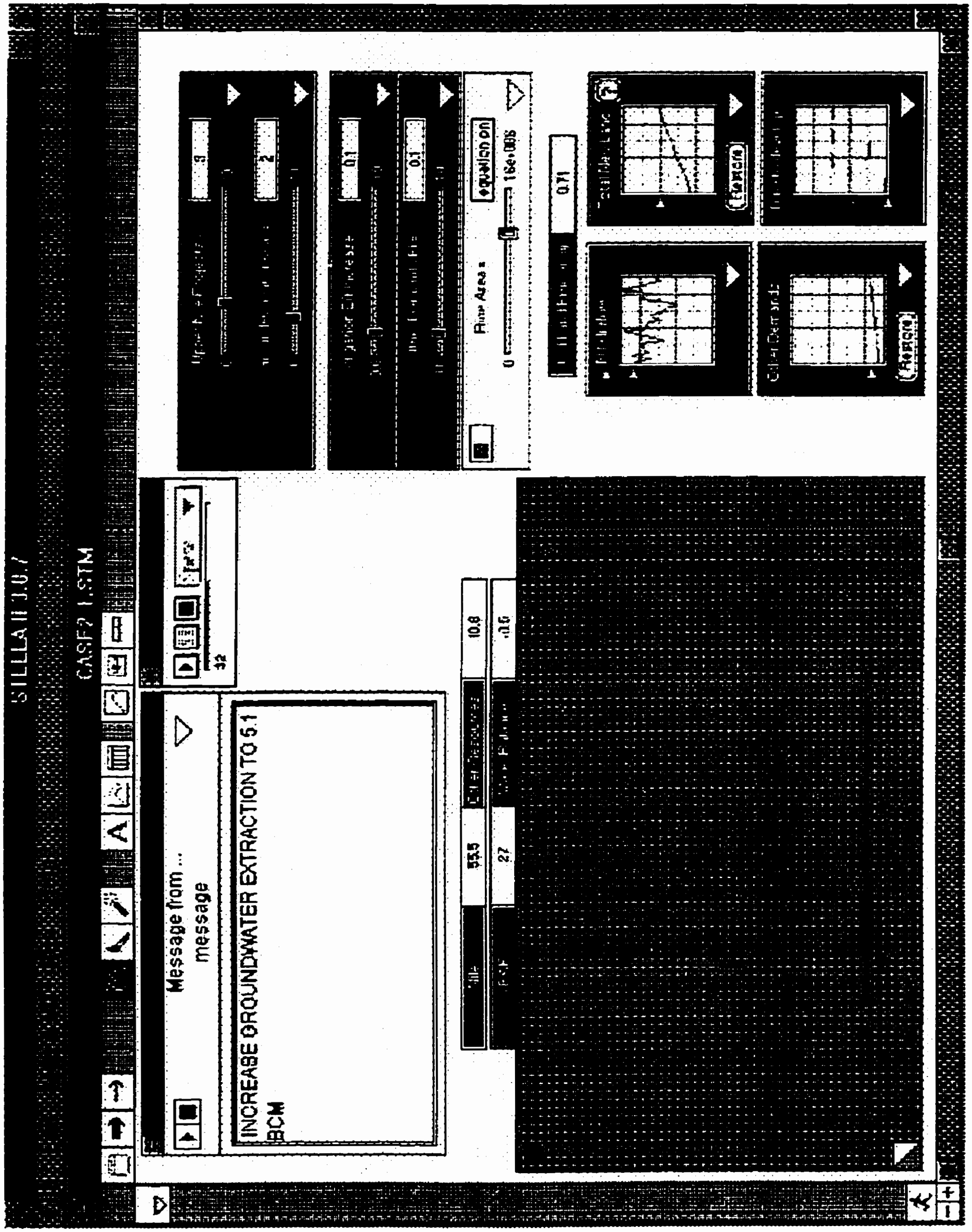


Figure 26: Application Graphical User Interface

6.5 SCENARIO GENERATION

Scenario generation process in the application is completely demand-dependent. Decision variables in the scenarios are the driving factors for water demand. Among these driving factors are the cropping pattern for old land, expansion plans for new land, and developments in both the domestic and industrial sectors. Scenarios generated for testing the future of a region must cover the whole range of possible developments. Extreme cases should also be tested to explore their effect on the system. Comparisons among scenarios results must be carried out according to a variety of indicators using one of the known multi-criteria analysis techniques. Although this step of policy analysis exceeds the scope of this research, it should be mentioned for future consideration.

Building scenarios for this application takes into consideration the expected development in Egypt. Four scenarios are suggested. The first scenario considers stable conditions with no development in agriculture or industry. The only development in this scenario is in the need for more domestic water as the population increases. The second scenario suggests increases in the water requirements over time due to average development in all economic sectors. The third scenario represents a case with a large increase in water demands due to an ambitious development plan in industrial and domestic water, while scenario 4 assumes a higher rate of land reclamation with moderate developments in other sector.

Decision variables in the application are dependent on the level of development planned in the main economic sectors; agriculture, domestic, and industry. Table 10 lists the decision variables for the application along with their levels for each of the developed scenarios. It should be noted that the values for domestic and industrial water demands are estimated using the detailed results in IWRMSD in NWSRU (1996). Also, other publications such as Khouzam (1995), and El-Shibini (1994) were used for agriculture development plans.

Table 10: Application Decision Variables Values for Scenarios

Decision Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
New Land (Feddans)	current 1.2 M	Max. 2.2 M	Max. 2.2 M	Max. 2.8 M
Domestic Water	Low	Med.	High	Med.
Industry Water	current	Med.	High	Med.

6.6 DEVELOPMENT PLANS

In order to make economic development in water use sectors possible, a set of water resources development plans must be prepared to combat any problem which might occur regarding the water sufficiency. Water resources development plans must depend on detailed study of the available resources in order to estimate their potential capacities. Then, studies measuring their various effects on the economic, social, political, and environmental levels should be conducted. Setting priorities of usage for development plans requires decision-makers to be aware of the implications of each plan. Using simulation models for water resources policy analysis helps planners identify the positive and negative impacts of each plan.

The role of the development plans sector in the application starts when a water shortage problem arises. This sector is responsible for providing the model with an alternative that is capable of solving the problem. A set of alternatives should be defined in this sector along with the priorities of implementation. The development plans sector, in its current form, is not capable of making a selection. Rather, it applies a given series of development plans for water sources and uses sequentially as defined by the decision-maker. For each of the development plans, the time required for implementation is considered and the model is sent back the number of time steps equal to the time required to implement the plan. Using this technique gives a continuous positive water balance throughout the whole simulation period.

The water resources development plans used in this application depend on many publications such as El-Qousy (1995) concerning the possibilities of water resources development for Egypt. Table 11 lists some of the recognized development possibilities in water resources and the expected water quantities to be added to the system.

Table 11: Possible Water Resources Development Plans

Type of Development		**Outcomes**	
Plan No.	**Description**	**Current**	**Potential**
1	Drainage Water Reuse (BCM)	4.7	7.7
2	Groundwater (BCM)	3.1	5.1
3	Reduction of Rice Area (Feddan)	Planned	750,000
4	Irrigation Efficiency Improvement	71.2%	80.0%
5	Domestic Network Improvement	50%	60%
6	Upper Nile Projects (BCM)	0.0	3.0

6.7 RESULTS

6.7.1 SCENARIO 1

Scenario 1 represents the current condition of the system without any further development in the future except for an increase in domestic water requirements due to population growth. The idea behind using this scenario is to create a base which can act as a reference for comparison purposes with other scenarios.

Results obtained from the model shows that for the 30 year simulated period, no water shortage problem will occur. However, there will be economic problem as the increased population requires more food and jobs. The economic balance of the country will tend to tilt towards payment rather than earning. The agriculture economic sector estimates the net present value (NPV) for the net revenues from agriculture to be 154.5 billion LE (Egyptian Pound). Figure 27 shows the simulated water balance under scenario 1 conditions.

6.7.2 SCENARIO 2

Scenario 2 represents the most likely case scenario for Egypt. The numbers used in this scenario portray the future situation as most decision makers' envision it. Average levels of development in agriculture, industry, and a moderate level of population growth according to statistics carried by local and international agencies are used estimating water requirements during the planning period.

Results obtained from the simulation indicate that the system requires the implementation of the development plan which was first suggested; increasing the drainage reuse water quantity from the present 4.7 BCM to the potential value of 7.7 BCM per year. The results also show that there will be a need for more development by the end of the planning period as the water balance in the last year tends to move to the negative side. The results obtained from the model concerning the economic net revenues from agriculture are higher than that of scenario 1, the base case, with 8.56 billion LE making an NPV of 163 billion LE. Figure 28 shows the water balance under scenario 2 conditions. In this Figure, The water balance falls below zero to the negative side in year 2015. The decision of implementing the drainage reuse increase plan is taken so the model goes back to year 2013, two years before the problem, and starts to increase the water supply throughout this two-year period. The final result in the same year, 2015, is that the water balance is increased by the planned quantity of three billion cubic meters.

6.7.3 SCENARIO 3

Scenario 3 presents an extreme case. The purpose of testing such case is to identify the dangers that might face the system under unexpected conditions in the future. This scenario suggests that the industrial sector is going to develop at a high rate (10% annually). Consequently, the water requirements for industry are going rise. Domestic water supply is expected to experience a potential increase as well. The agriculture sector conditions are similar to those of the previous case, scenario 2.

As expected when developing the scenario, the water resources system could not handle the excessive water demands from the domestic and industrial sectors without initiating multiple water resources development programs. The simulation model had to assume the implementation of the first four development plans, according to the sequence in Table 11, in order to satisfy the increasing need for water. Although the expected revenues from the excessive industrialization plans are very promising, some other aspects should be taken into consideration. One aspect is the cost of implementing the four suggested plans. Another aspect is the effects of these plans on the ecosystem. The simulation results for the water balance using scenario 3 are shown in Figure 29. The Figure shows an earlier start for development than in the previous scenario. In the years 2006 and 2008, the first two plans are required. However, in the year 2013, the third and fourth plan are required. The results show that in the year 2014 it was decided that the third plan has to be implemented in 2012, two years earlier. However, the water shortage problem reoccurred in the year 2016 meaning that the fourth plan, taking 4 years for implementation, must begin at the same time with the third plan, year 2012.

6.7.4 SCENARIO 4

Another extreme case is presented in scenario 4. An ambitious plan for land reclamation is to be implemented along the planning period. Newly introduced land reclamation plan increases the current 1.2 million Feddans to 2.8 million at the end of the 30 year period, year 2020.

The results also show an ample increase in the NPV from agriculture of about 14.5 billion LE over the planning period to reach 169 billion LE. Figure 30 shows the simulated water balance for scenario 4.

6.8 DISCUSSION

The object-oriented water resources policy model is tested on the water resources system of Egypt. The whole country is considered as one region. The main water source, the River Nile, and the major controlling structure, the High Aswan Dam, are presented in detail. Other sources such as groundwater, drainage reuse, and sewage treatment are summed in a single object. This assumption is rationalized on the basis that these sources constitute less than 20% of the total available water resources. Agriculture, as the highest water consumption sector, is also presented in detail while other demands such as domestic and industry are summed in one object.

Four scenarios are tested. The first scenario assumes that the current conditions governing the water resources system will prevail for the 30 year planning period. A slight increase in domestic water use occurs due to a population increase. Other sectors such as agriculture and industry remain the same without any development. The second scenario is a 'most-likely' case with moderate development in both agriculture and industry to accommodate the population increase. The last two scenarios introduce some extreme conditions concerning water requirements. The third scenario considers a potential increase in industry which translates into higher water demands. The last scenario assumes an expansion of land reclamation plans.

Figure 27: Water Balance - Scenario 1

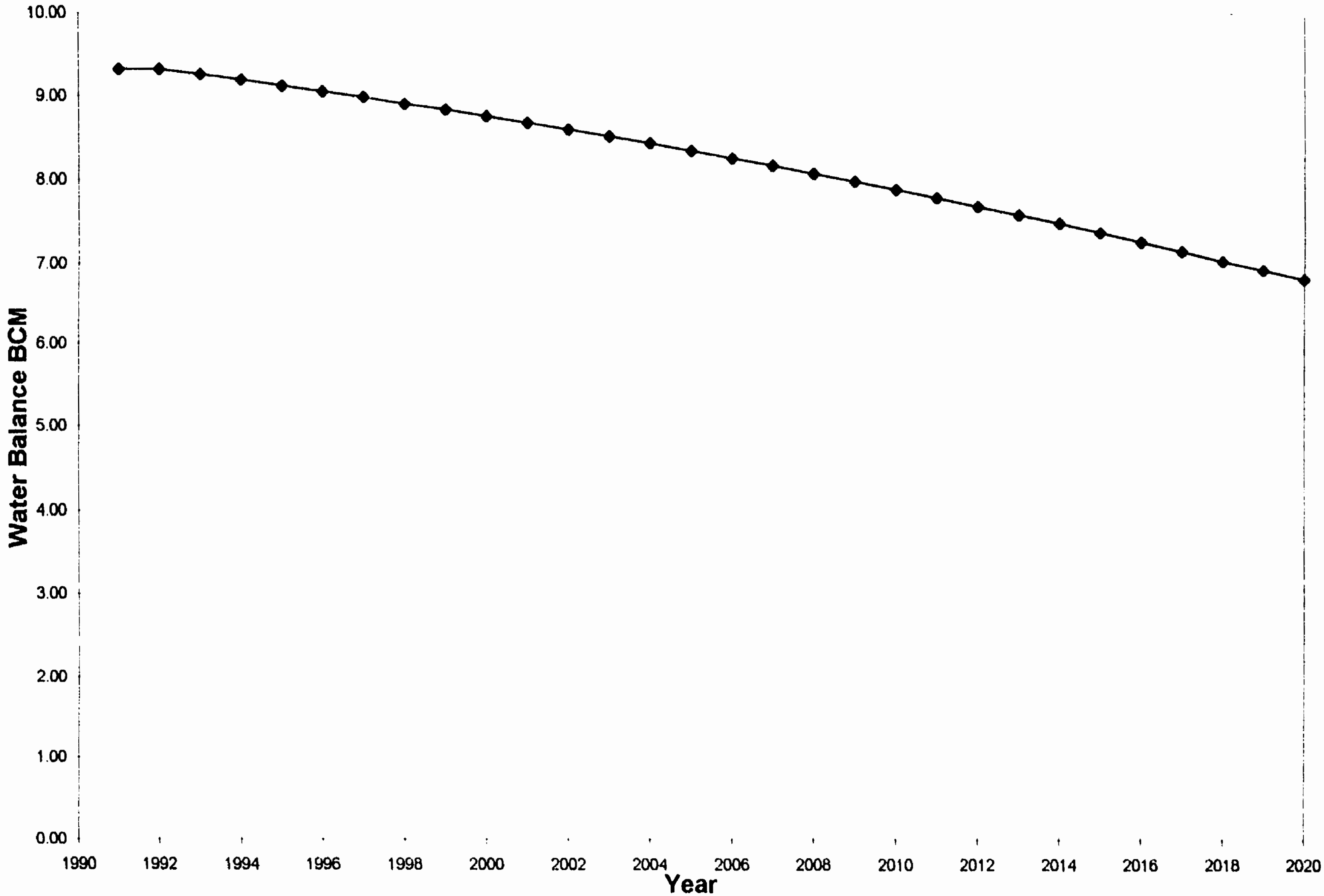


Figure 28: Water Balance - Scenario 2

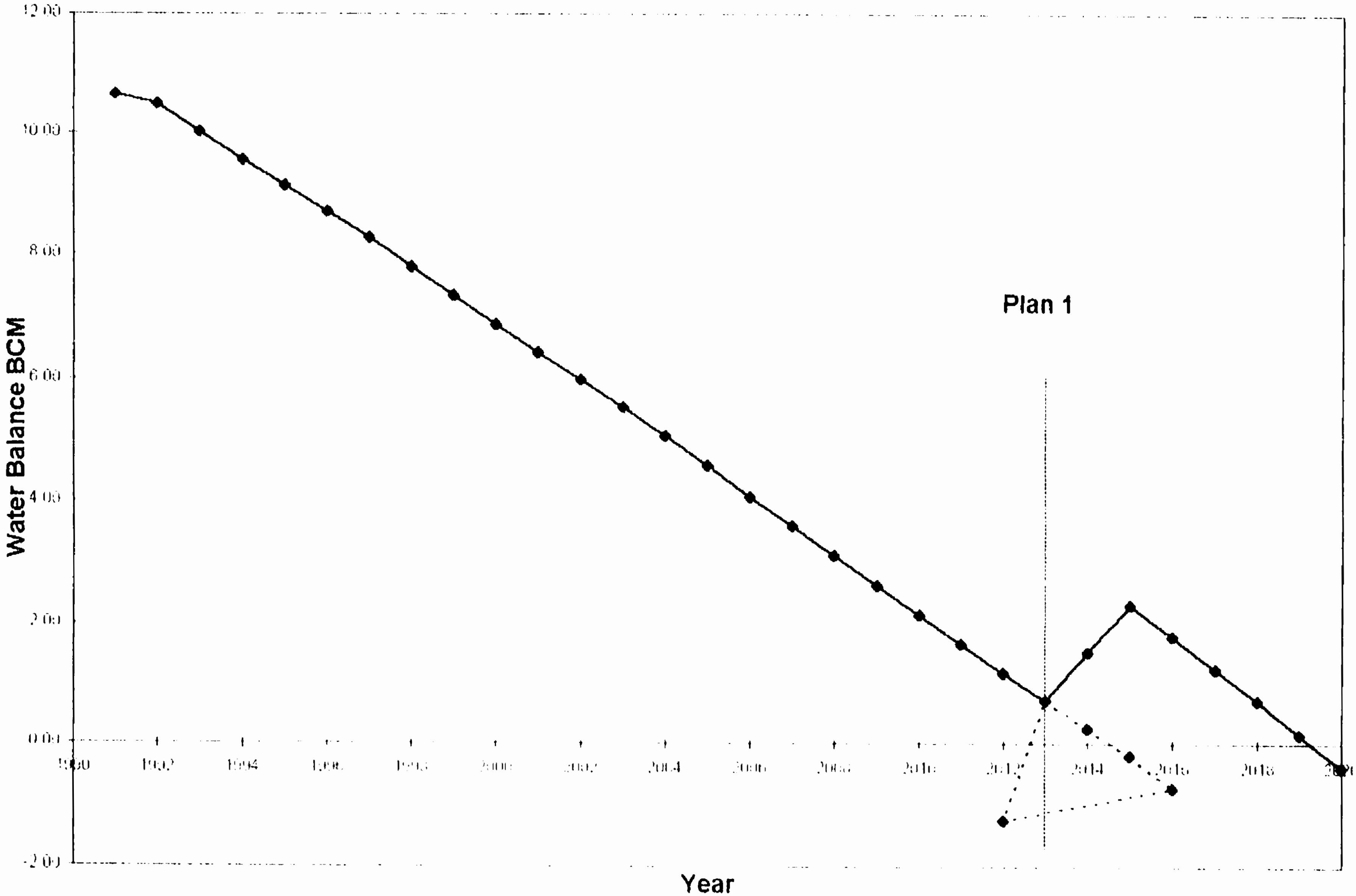


Figure 29: Water Balance - Scenario 3

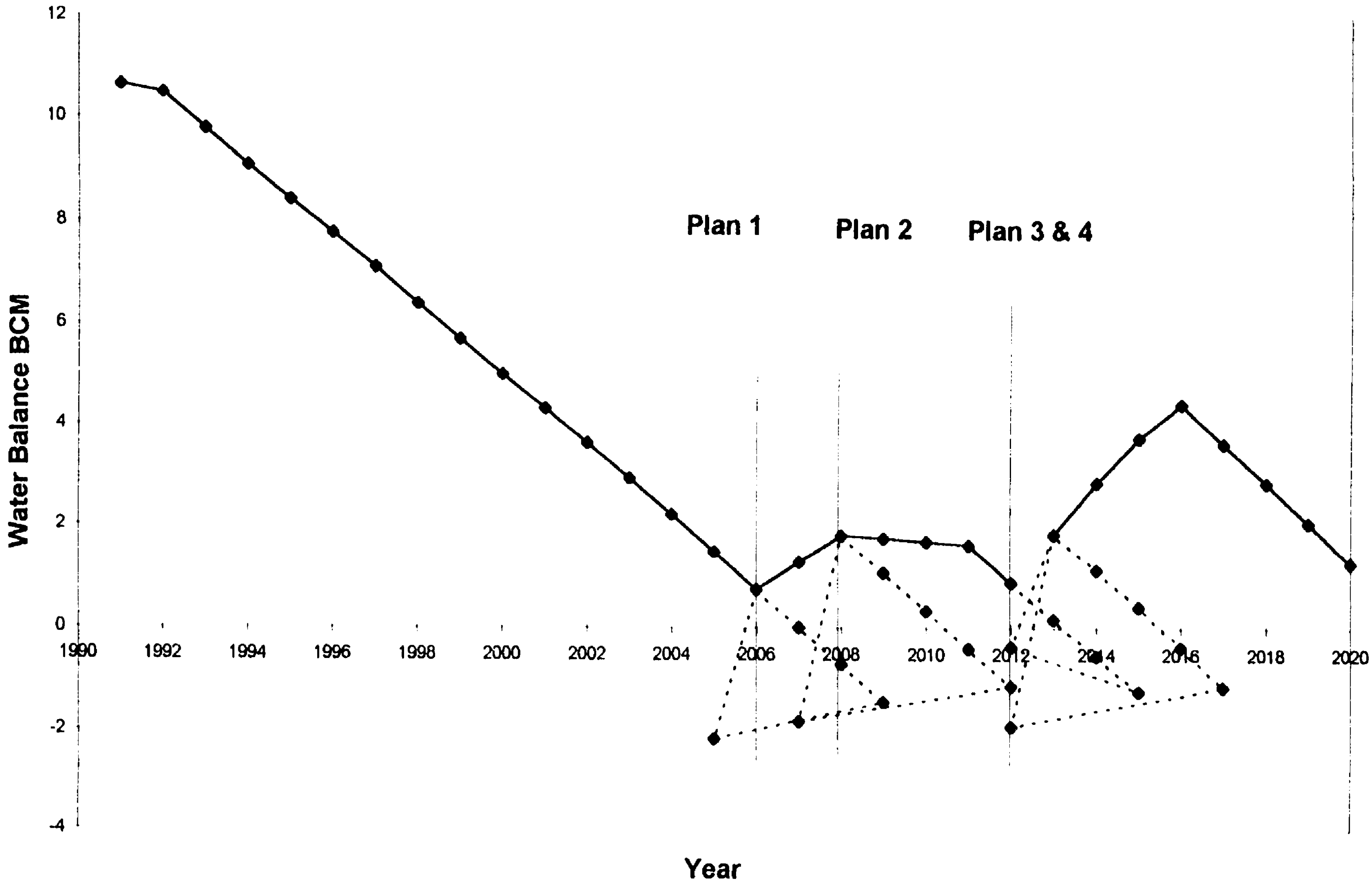
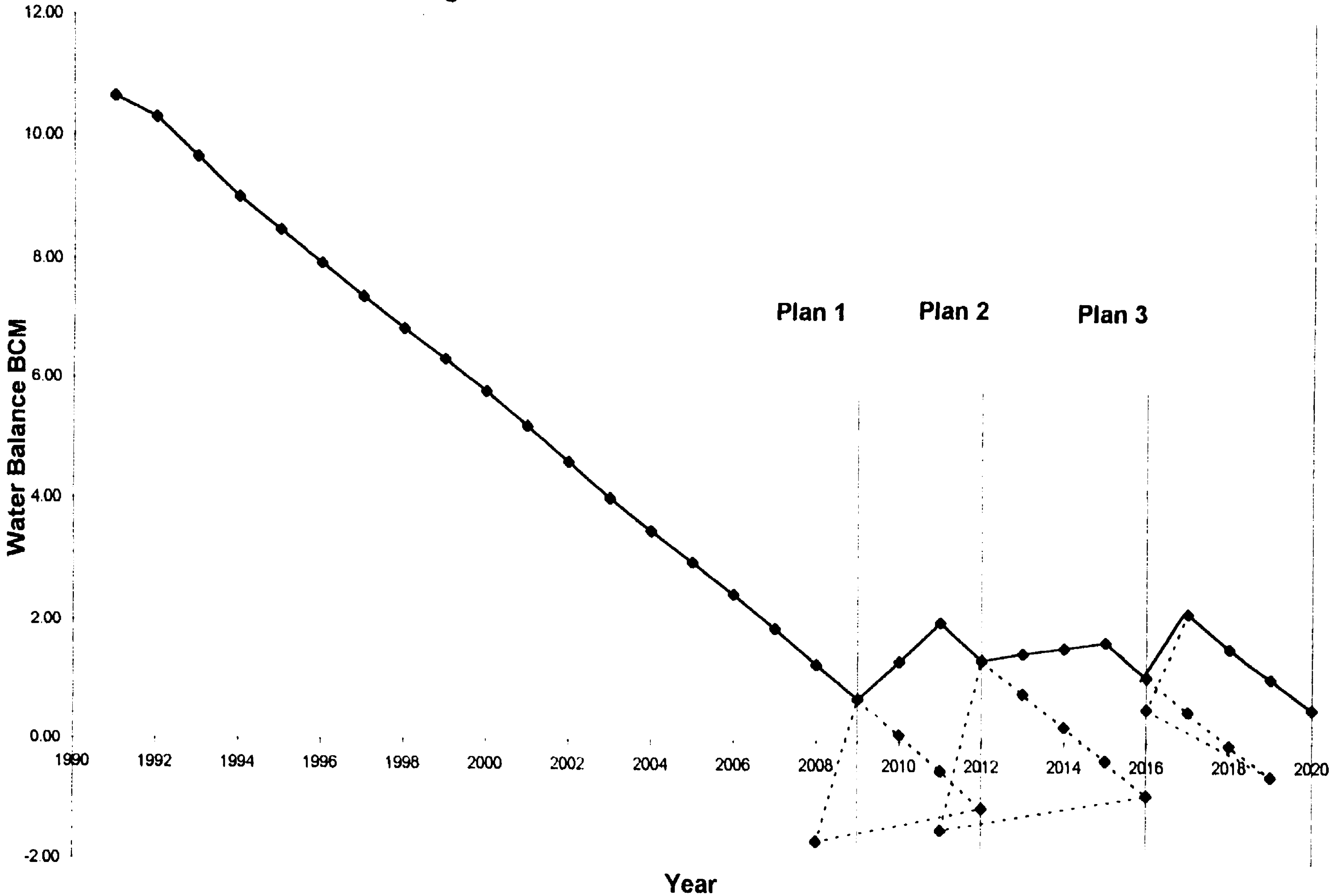


Figure 30: Water Balance - Scenario 4



Results obtained from the four scenarios reflect the need to expand the existing water resources system. Although the base-case scenario did not require the implementation of any development, all other scenarios required that some additions to the available resources be made in order to satisfy future needs. The level of required development differed from one scenario to the other according to water consumption rates required for the sector to be developed. The economic indicator used in the model, NPV, reflected the effects of agriculture expansion on the economy. Results show a potential increase in the value of the NPV for both scenarios 2 and 4 when compared to the base case. Unfortunately, data availability limited the calculations of the NPV to agriculture only.

The model results for scenarios 2 through 4 prove that the feedback technique described in the framework is applicable. The simulation model is capable of adjusting the water balance according to water requirements throughout the planning period in a dynamic manner using the predefined alternatives. The feedback technique facilitated the process of water policy analysis as it continuously investigated the system status and identified the necessary actions to be taken to protect the system from any water shortage problem by introducing a suitable alternative.

This application for water resources system policy analysis in Egypt shows that the use of the object-oriented approach is very useful. The modifications applied to the general model, although they are many, do not take much effort. The reusability factor associated with the object-oriented techniques makes it possible to take previously developed components from existing models and connect them to this one. Finally, the flexibility which allows the model specifications to be changed to accommodate a special case or to include new components that were not available in the original model facilitates applying the model to this case study.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL

The work presented in the thesis is an attempt to introduce one of the up-to-date modeling approaches, the object-oriented approach, into the world of water resources systems policy analysis modeling. An eight-stage modeling framework is developed and explained within the water resources system context. Then, one of the object-oriented modeling environments is used to develop a general water resources policy analysis model. Finally, the general model is applied to a case study, Egypt's water resources system, to investigate the advantages of using an object-oriented approach over traditional programming approaches. The application denotes a great potential for using this approach rather than traditional ones. Among the advantages are the clearer understanding of the behavior of each of the modeled components, ease of model modification to accommodate certain aspects of the modeled system, and reusability of previously modeled components.

7.2 THE MODELING FRAMEWORK

The modeling framework developed describes in detail the steps to be taken in order to develop a water resources system policy analysis model. The approach begins by identifying the system's components and categorizing them into super-classes, classes, and subclasses according to a specified hierarchy following the object-oriented analysis rules.

Then, the dynamic behavior of each component as well as the dynamic interaction among system components are identified. Great attention must be given to these steps as they constitute the base upon which the whole modeling procedure depends. The next steps represent the policy aspects of the model such as developing future forecasts for demands, and identifying possible problems along with suggested actions to be taken to overcome these problems. Effects of water resources policies on the system are studied through a group of indicators. The selection of indicators is highly dependent on the characteristics of the system studied, as well as data availability.

The object-oriented framework for water resources policy analysis can be considered of great benefit to water resources planners and decision-makers. This approach offers transparency into the system rather than structured top-down approaches. The process used in developing a model in an object-oriented environment allows for understanding the behavior of the system, as it creates a clear picture of the components. The class-categorizing process makes it more convenient to deal with a model by introducing the characteristics of similar objects only once. The dynamic behavior of each of the model components is explicitly established within the component.

7.3 MODEL DEVELOPMENT AND APPLICATION

The developed modeling framework is implemented. The model development process using an object-oriented environment is carried out through the use of STELLA II. This kind of tool provides decision-makers or water resources planners with a graphical, object oriented environment. Model development using STELLA II does not require extensive knowledge of programming languages. Therfore, users are able to quickly construct, and easily interact with simulation models, and presents results clearly to a wide audience. In general, model development through such environments takes less effort, less computer knowledge, and less time, since the internal consistency of the simulation models is checked automatically. The use of object oriented programming modeling environments has allowed planners and decision-makers to have a better understanding of the potential benefits and damages created by water resources projects or their operating policies. The application shows that the use of object-oriented environments in water resources planning and policy analysis is powerful enough to create a transparent and flexible model. It is also clear that the model use is not limited to a rigid set of alternatives. Rather, the model is able to answer a wide range of 'what-if' questions with minor modifications in the model such as modification or addition of model components. The transperancy of the model makes it easy to strengthen in the future without the need to refer to the original model developer.

The general model application to the case study of Egypt's water resources system proves the applicability of the framework. For this case study, components of the water resources system in Egypt are simulated and the overall water balance is the main concern of the application. The feedback technique used in the model is responsible for continuously checking the water balance and, in the case of a water shortage, to introduce one of the possible alternatives to prevent its occurrence.

Results obtained from the model for the case study based on Egypt's water resouces system shows that lack of water can place constraints on the economic development of the country. Population increase is one of the major factors affecting water requirements. Food, drinking water, and jobs for the increasing number of people strain the existing available water resources. Economic development of the country is possible only by increasing water resources or by increasing water use efficiency. Out of the four scenarios tested, three scenarios require the implementation of certain development projects. The level of the water resources development required is highly dependent on the suggested development in the economic sectors. The results also show the effect of agricultural expansion on the economy. The calculated NPV for the agriculture production potentially increases with increasing reclamation plans.

CHAPTER 8

FUTURE WORK

The work presented in this thesis can be considered a starting point for an organized object-oriented modeling in the field of water resources policy modeling. The framework addresses the basics of using object-oriented technology in this field. Several additions can be made to framework as well as the general model.

It would be advantagous to include water quality analysis in the model development process. Many previous models have studied local water quality problems on a highly detailed level. However, the aggregate level for water quality studies is not yet developed. The model can include a water quality component which identifies water quality problems and suggests different methodologies to solve the problems.

The application of the general model to Egypt's water resources system proved the usefulness of the general model. However, lack of data put some limitations to this application. This appication can be expanded to include more decision variables in all economic sectors. Addition can also be made to the indicators in order to reflect a more realistic picture of the water resources system status as well as the economic, social, and environmental conditions.

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APPENDICES

APPENDIX 1

GENERAL MODEL CHART

BALANCE

☐ T3(t) = T3(t - dt) + (T1 - T2) * dt
INIT T3 = 0
INFLOWS:
T1 = if (plan>0) then (Time_to_develop+1) else 0
OUTFLOWS:
T2 = 1

☐ total_time_back(t) = total_time_back(t - dt) + (time_back) * dt
INIT total_time_back = 0
INFLOWS:
time_back = IF (Time_to_develop>0) then (Time_to_develop+1) else 0

☐ Water_Balance(t) = Water_Balance(t - dt) + (in - out - Balance) * dt
INIT Water_Balance = 0
INFLOWS:
in = Resources
OUTFLOWS:
out = Demands
Balance = Water_Balance

○ beep = if time_back>0 then SOUND(1) else 0

○ TERMINATE = if time_period>=30 then 1 else 0

○ time_period = ROUND(TIME-total_time_back)

⊘ Time_to_develop = GRAPH(plan)
(0.00, 0.00), (1.00, 3.00), (2.00, 2.00), (3.00, 2.00), (4.00, 2.00), (5.00, 0.00), (6.00, 0.00)

DEMANDS

☐ D3(t) = D3(t - dt) + (DM_1_RED - RF_1_INC) * dt
INIT D3 = 0
INFLOWS:
DM_1_RED = IF PLAN=4 THEN Demand_1_RF ELSE 0
OUTFLOWS:
RF_1_INC = D3/T3

☐ D4(t) = D4(t - dt) + (DM_2_RED - RF_2_INC) * dt
INIT D4 = 0
INFLOWS:
DM_2_RED = IF PLAN=3 THEN Demand_2_RF ELSE 0
OUTFLOWS:
RF_2_INC = D4/T3

☐ DM_1_RF(t) = DM_1_RF(t - dt) + (RF_2_INC) * dt
INIT DM_1_RF = 0
INFLOWS:
RF_2_INC = D4/T3

DM_2_RF(t) = DM_2_RF(t - dt) + (RF_1_INC) * dt
INIT DM_2_RF = 0
INFLOWS:
RF_1_INC = D3/T3
Demands = demand_1*(1-DM_1_RF)+demand_2*(1-DM_2_RF)
Demand_1_RF = 0.1
Demand_2_RF = .1
demand_1 = GRAPH(time_period)
(1.00, 18.3), (4.22, 19.5), (7.44, 21.0), (10.7, 22.6), (13.9, 24.3), (17.1, 25.6), (20.3, 26.5), (23.6, 27.6) (26.8, 27.9), (30.0, 28.0)
demand_2 = GRAPH(time_period)
(1.00, 17.0), (2.00, 17.0), (3.00, 17.0), (4.00, 17.0), (5.00, 17.0), (6.00, 17.0), (7.00, 17.0), (8.00, 17.0) (9.00, 17.0), (10.0, 17.0), (11.0, 17.0), (12.0, 17.0), (13.0, 17.0), (14.0, 17.0), (15.0, 17.0), (16.0, 17.0) (17.0, 17.0), (18.0, 17.0), (19.0, 17.0), (20.0, 17.0), (21.0, 17.0), (22.0, 17.0), (23.0, 17.0), (24.0, 17.0) (25.0, 17.0), (26.0, 17.0), (27.0, 17.0), (28.0, 17.0), (29.0, 17.0), (30.0, 17.0)

PLANS

PL(t) = PL(t - dt) + (Plan_chg) * dt
INIT PL = 0
INFLOWS:
Plan_chg = if (Water_Balance<0) AND ((T3=0) OR (time_back>0)) AND((DS1>=0) or (DS3<0)) then 1 else 0
Dem_1_RF = if PL>=3 then 0.1 else 0
Dem_2_RF = if PL>=4 then 0.1 else 0
DP1 = DELAY(PL,1)
DS1 = DELAY(Water_Balance,1)
DS3 = DELAY(Water_Balance,3)
plan = if NOT(PL=DP1) then (PL) else 0

RESOURCES

resource_1_add(t) = resource_1_add(t - dt) + (add_to_1) *dt
INIT resource_1_add = 0
INFLOWS:
add_to_1 = Res_1_inc/T3
resource_2(t) = resource_2(t - dt) + (add_to_2) * dt
INIT resource_2 = 25
INFLOWS:
add_to_2 = Res_2_inc/T3
Res_1_inc(t) = Res_1_inc(t - dt) + (Resource_1_Development - add_to_1) * dt
INIT Res_1_inc = 0
INFLOWS:
Resource_1_Development = if plan=1 then Res_1_Dev_Plan else 0
OUTFLOWS:

add_to_1 = Res_1_inc/T3

Res_2_inc(t) = Res_2_inc(t - dt) + (Resource_2_Development - add_to_2) * dt
INIT Res_2_inc = 0
INFLOWS:
Resource_2_Development = if plan =2 then Res_2_Dev_Plan else 0
OUTFLOWS:
add_to_2 = Res_2_inc/T3

Resources = resource_2+Resource_1

Resource_1 = resource_1_add+In_Resource_1

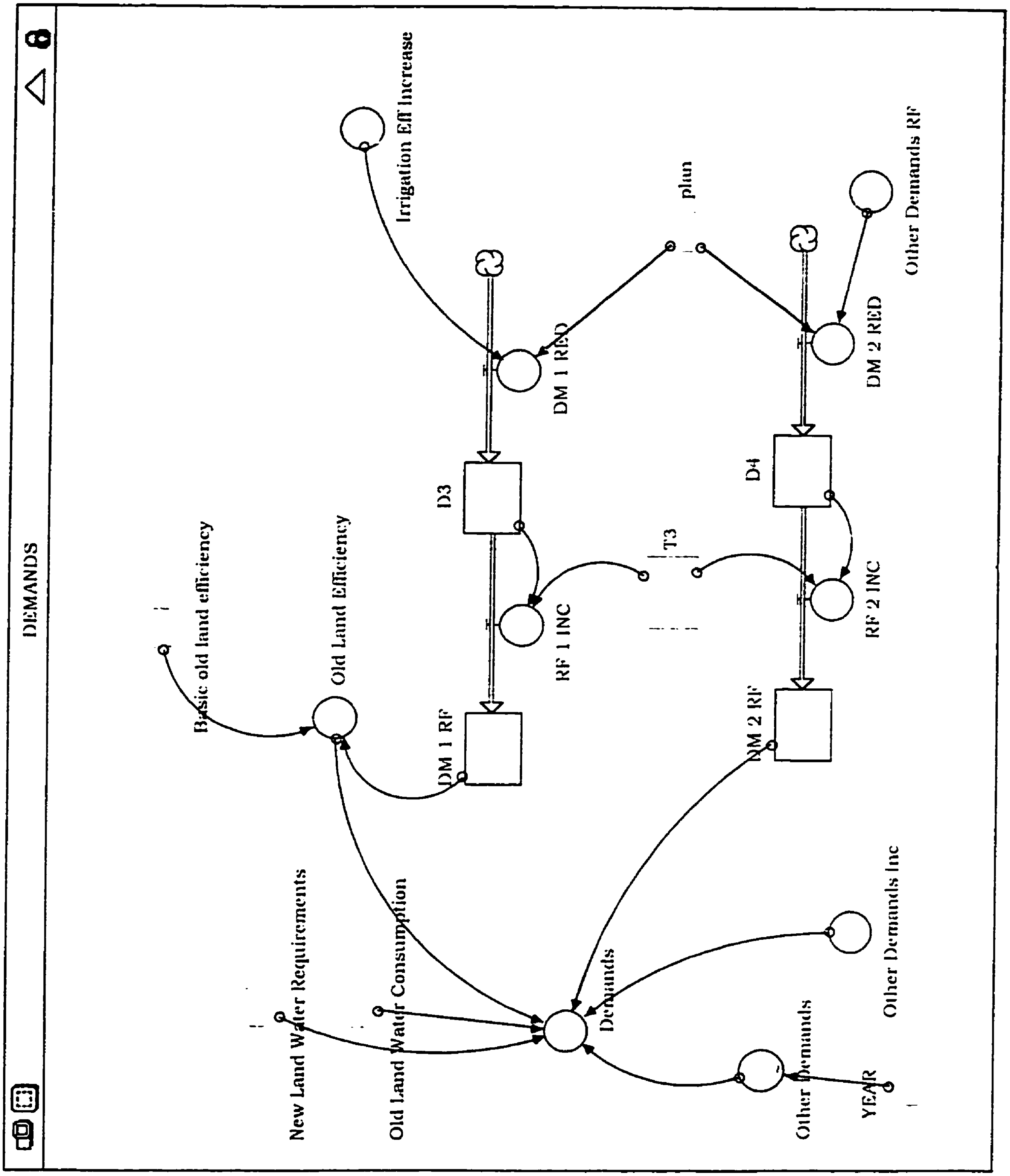
Res_1_Dev_Plan = 3

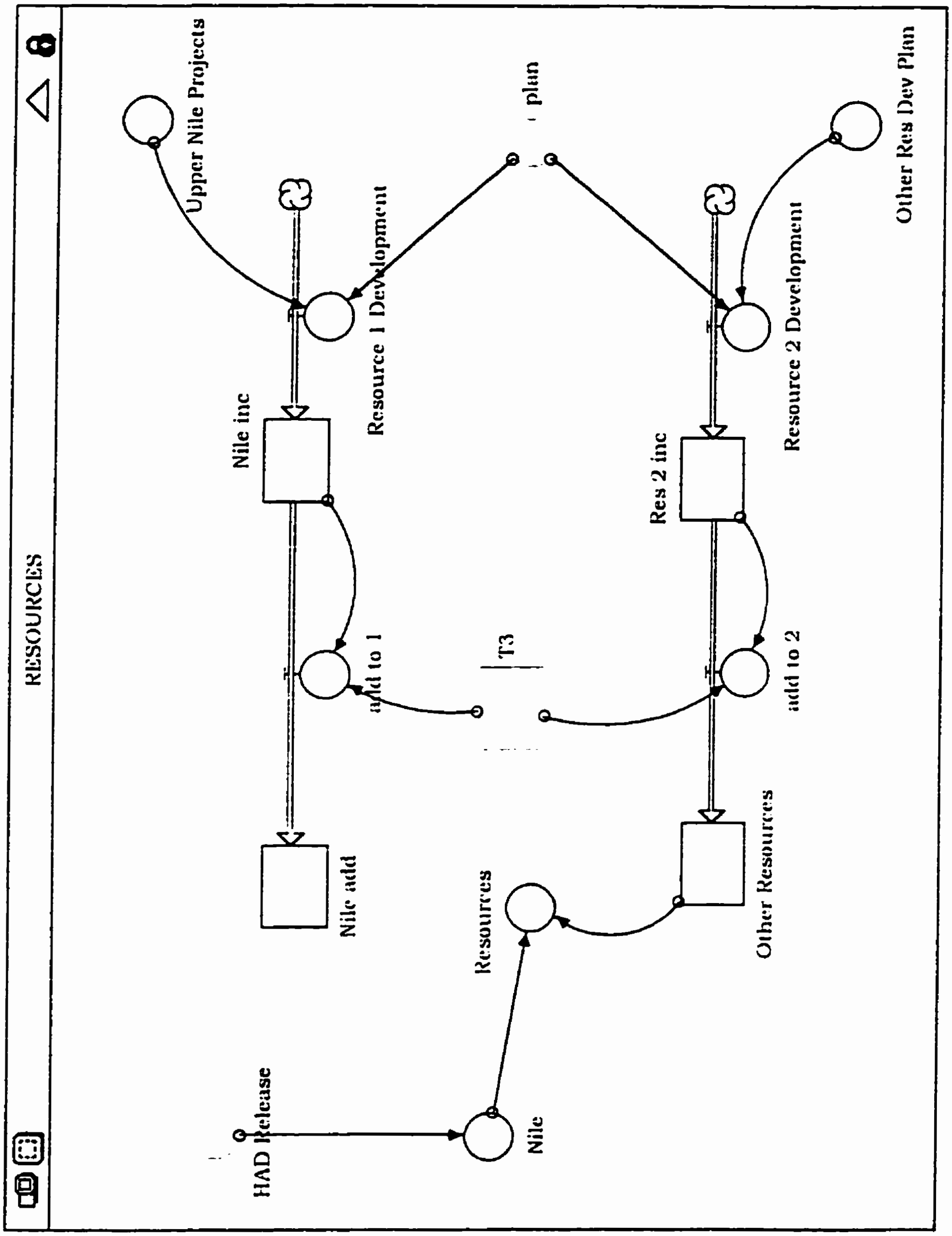
Res_2_Dev_Plan = 2

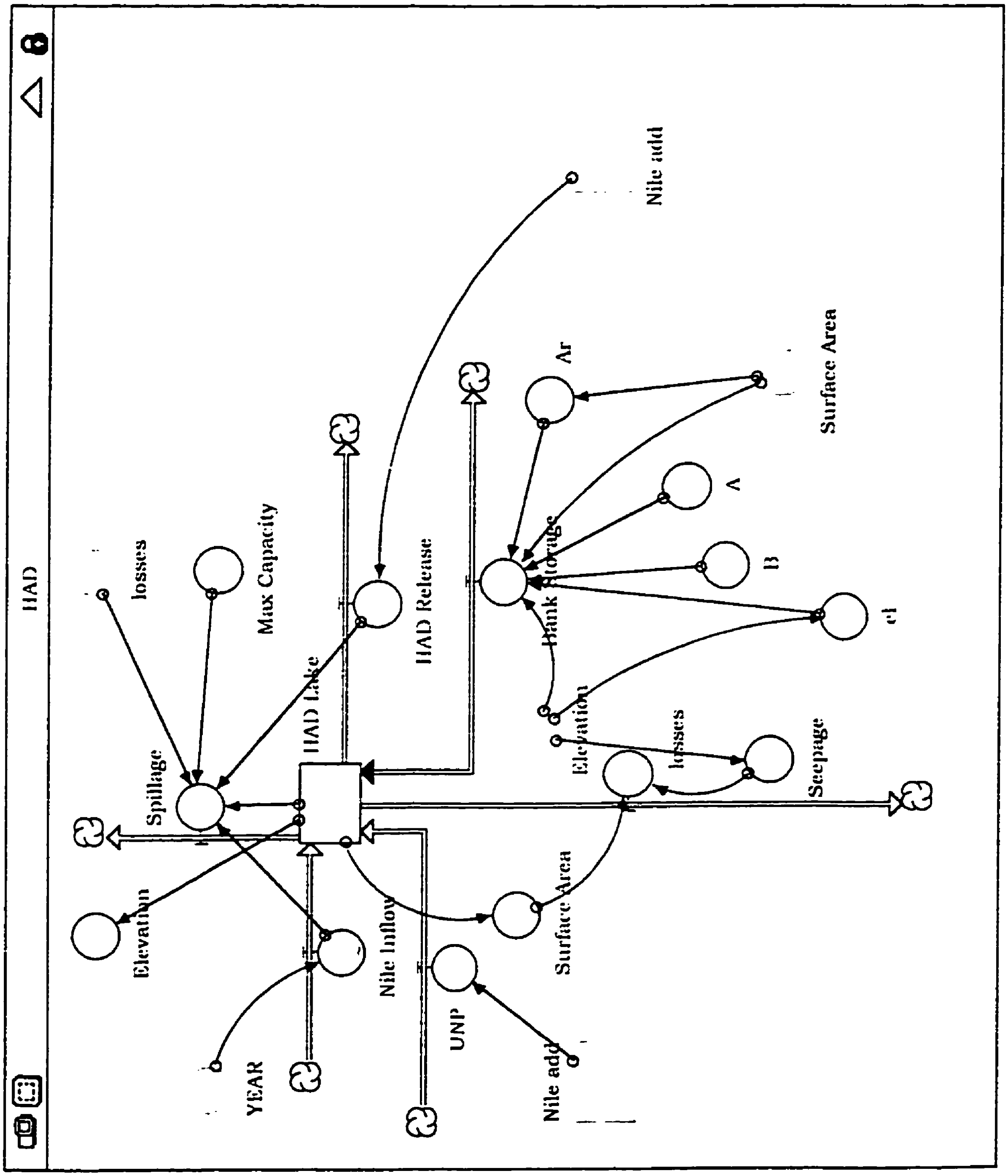
In_Resource_1 = GRAPH(time_period)
(1.00, 14.8), (3.90, 14.8), (6.80, 14.4), (9.70, 12.9), (12.6, 11.7), (15.5, 11.2), (18.4, 11.0), (21.3, 12.1), (24.2, 14.4), (27.1, 16.6), (30.0, 17.2)

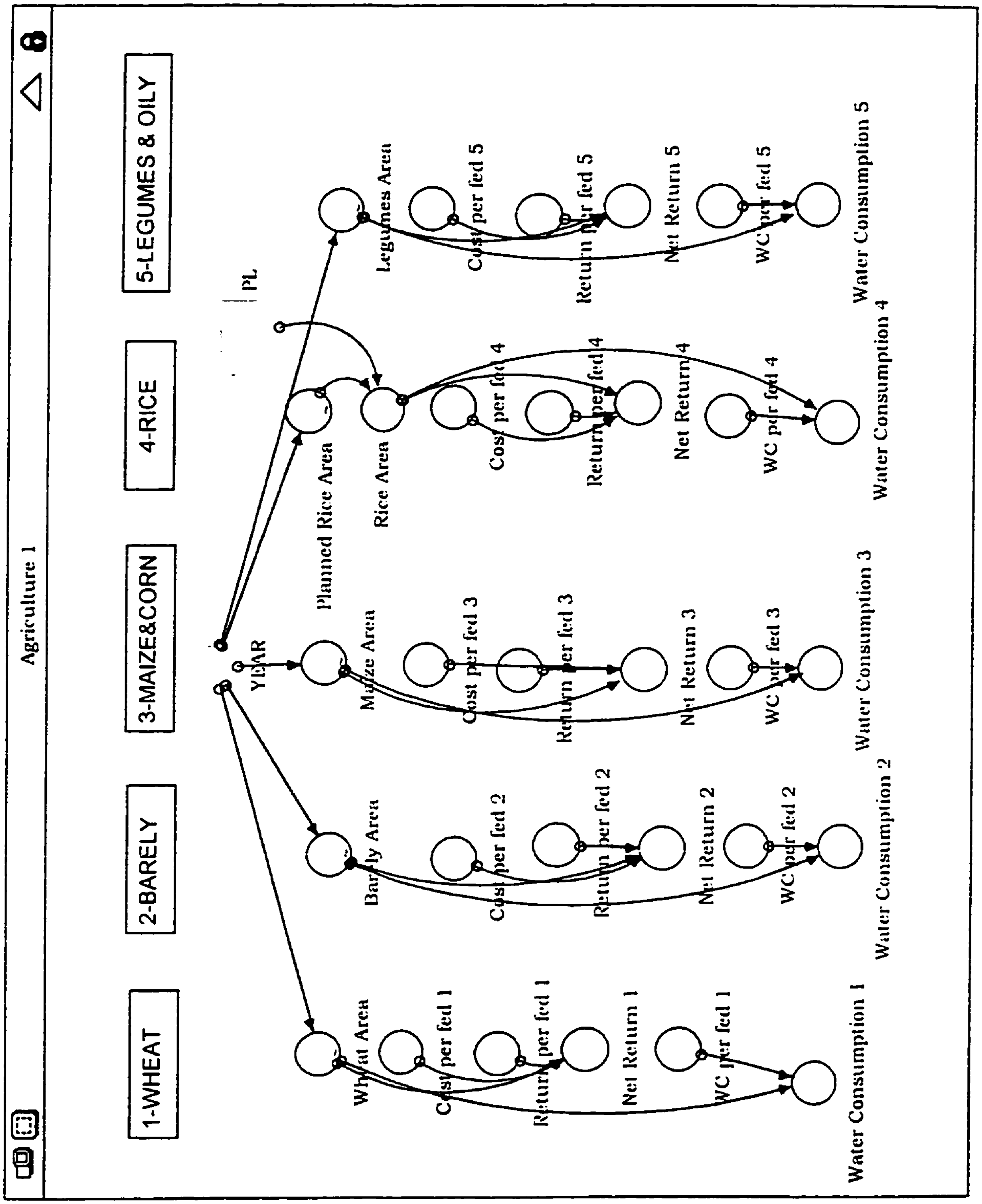
APPENDIX 2

CASE STUDY MODEL CHART

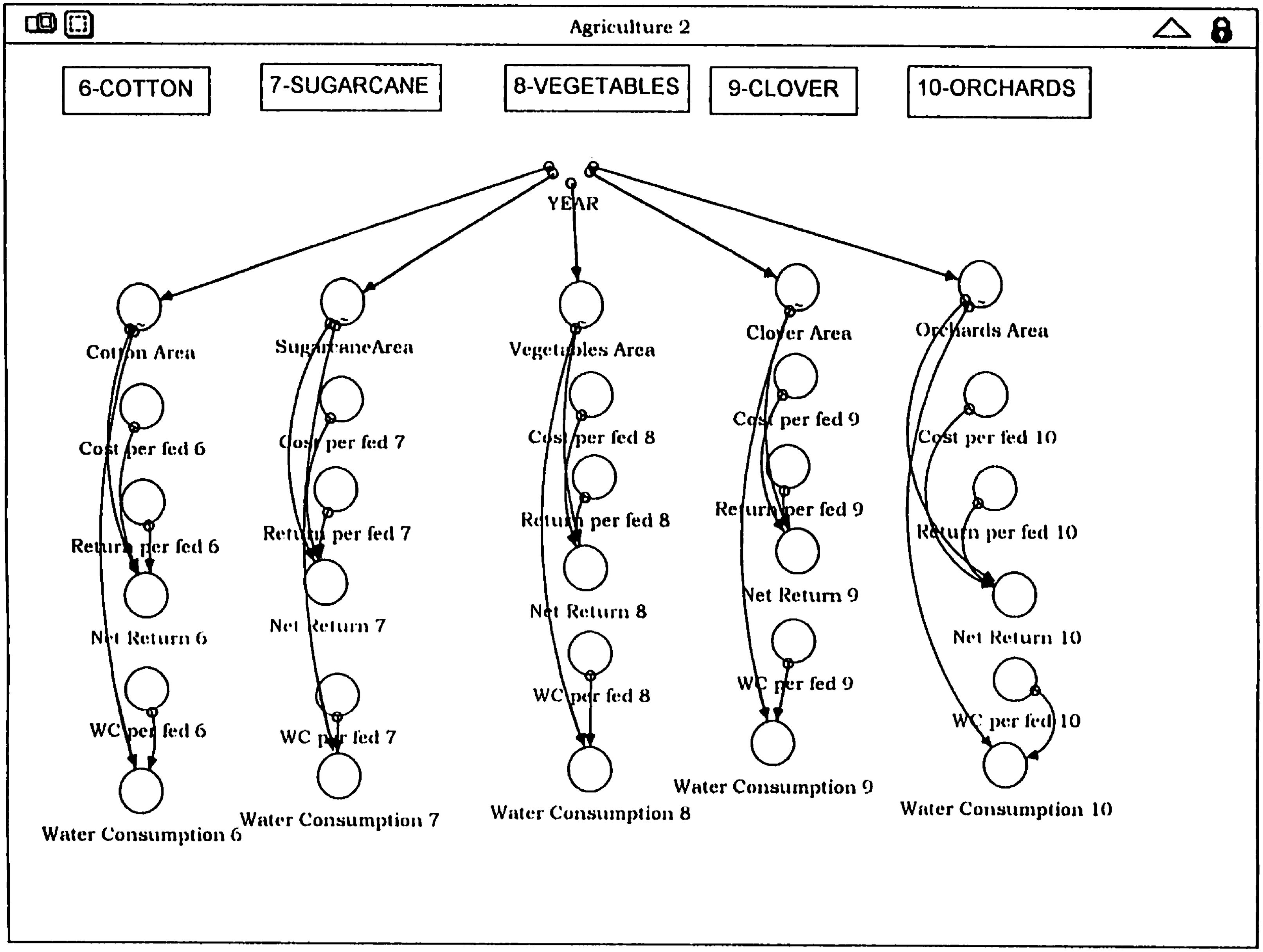

DEMANDS
Irrigation Eff Increase
plan
Other Demands RF
DM 1 RED
DM 2 RED
D3
D4
T3
Basic old land efficiency
Old Land Efficiency
RF 1 INC
RF 2 INC
DM 1 RF
DM 2 RF
New Land Water Requirements
Old Land Water Consumption
Demands
Other Demands Inc
Other Demands
YEAR

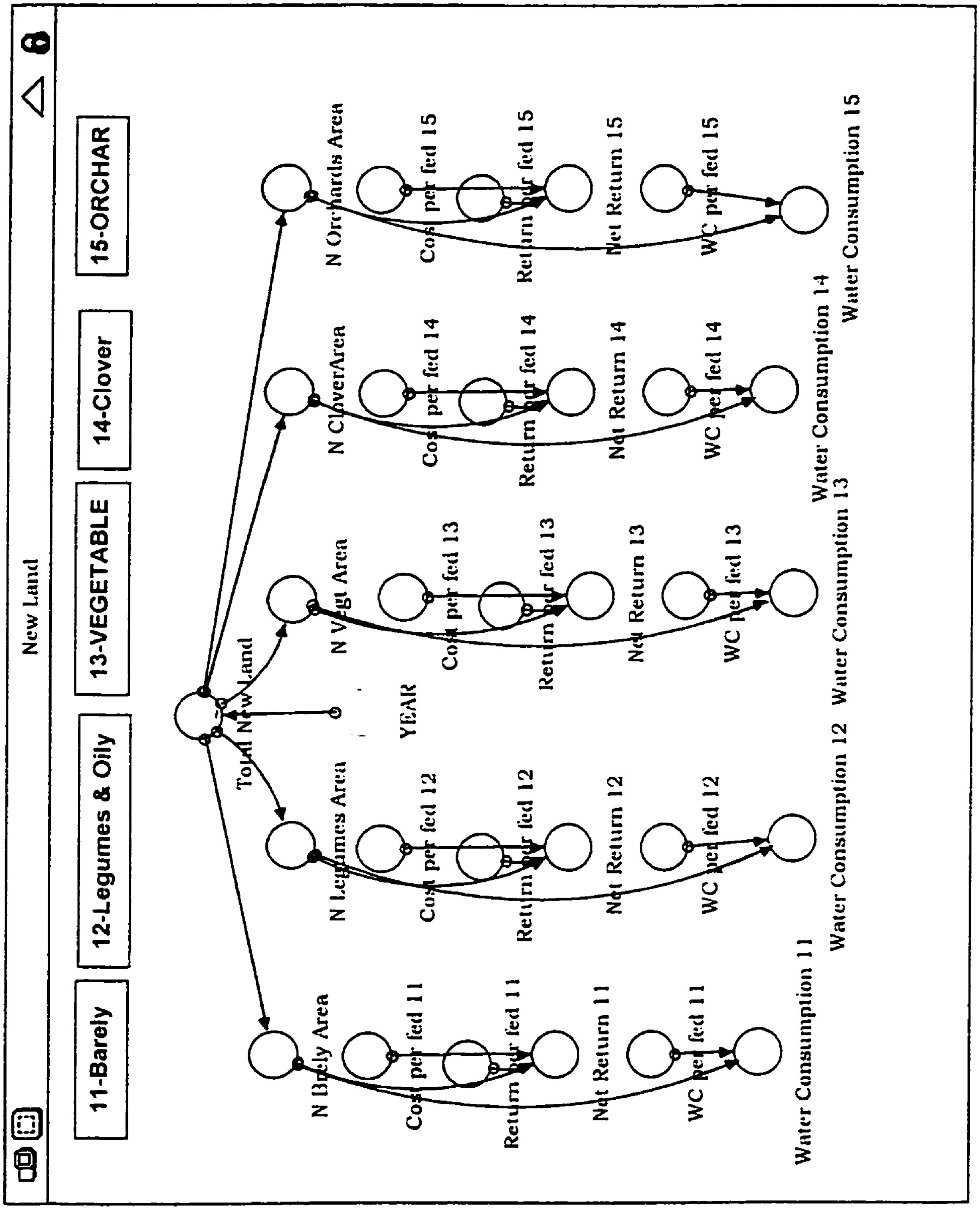

RESOURCES
Upper Nile Projects
plan
Other Res Dev Plan
Resource 1 Development
Resource 2 Development
Nile inc
Res 2 inc
add to 1
add to 2
T3
Nile add
Other Resources
Resources
Nile
HAD Release


HAD
losses
Max Capacity
Spillage
HAD Lake
HAD Release
Elevation
Nile Inflow
YEAR
UNP
Nile add
Surface Area
losses
Seepage
Elevation
Bank Storage
Ar
A
B
el
Surface Area
Nile add

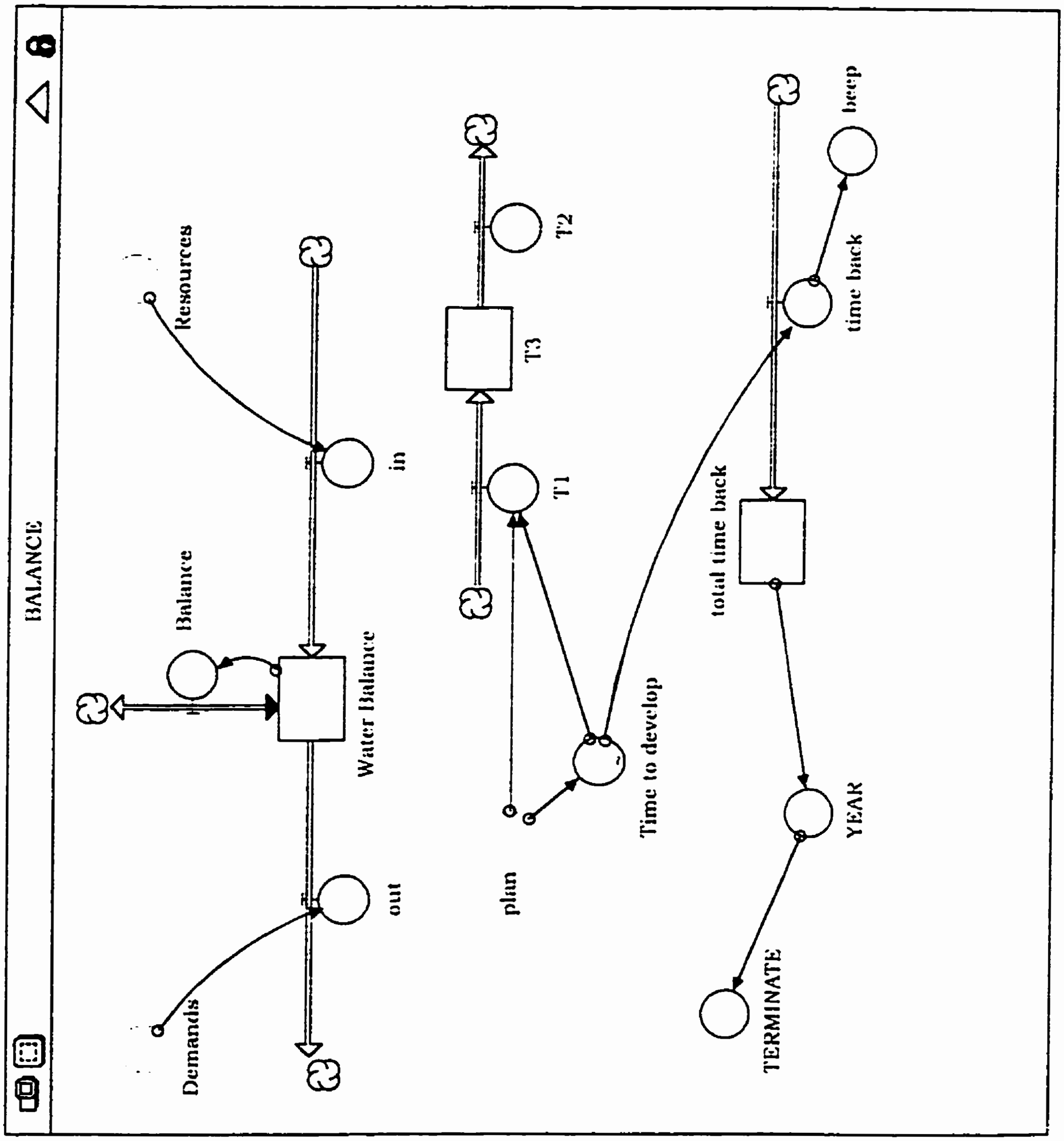


Agriculture 1
1-WHEAT
2-BARELY
3-MAIZE&CORN
4-RICE
5-LEGUMES & OILY
YEAR
PL
Wheat Area
Cost per fed 1
Return per fed 1
Net Return 1
WC per fed 1
Water Consumption 1
Barely Area
Cost per fed 2
Return per fed 2
Net Return 2
WC per fed 2
Water Consumption 2
Maize Area
Cost per fed 3
Return per fed 3
Net Return 3
WC per fed 3
Water Consumption 3
Planned Rice Area
Rice Area
Cost per fed 4
Return per fed 4
Net Return 4
WC per fed 4
Water Consumption 4
Legumes Area
Cost per fed 5
Return per fed 5
Net Return 5
WC per fed 5
Water Consumption 5

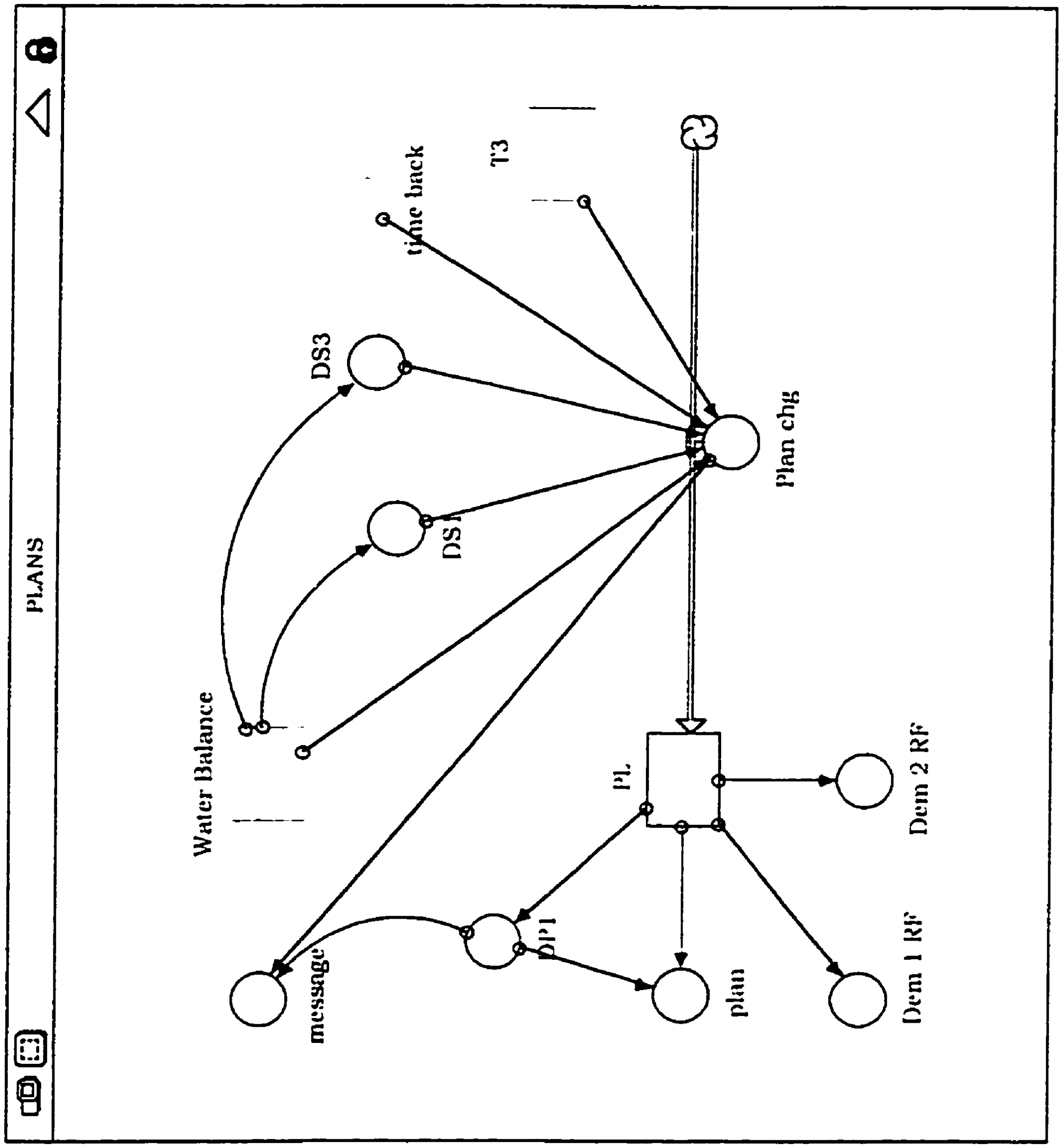

Agriculture 2
6-COTTON
7-SUGARCANE
8-VEGETABLES
9-CLOVER
10-ORCHARDS
YEAR
Cotton Area
Cost per fed 6
Return per fed 6
Net Return 6
WC per fed 6
Water Consumption 6
SugarcaneArea
Cost per fed 7
Return per fed 7
Net Return 7
WC per fed 7
Water Consumption 7
Vegetables Area
Cost per fed 8
Return per fed 8
Net Return 8
WC per fed 8
Water Consumption 8
Clover Area
Cost per fed 9
Return per fed 9
Net Return 9
WC per fed 9
Water Consumption 9
Orchards Area
Cost per fed 10
Return per fed 10
Net Return 10
WC per fed 10
Water Consumption 10

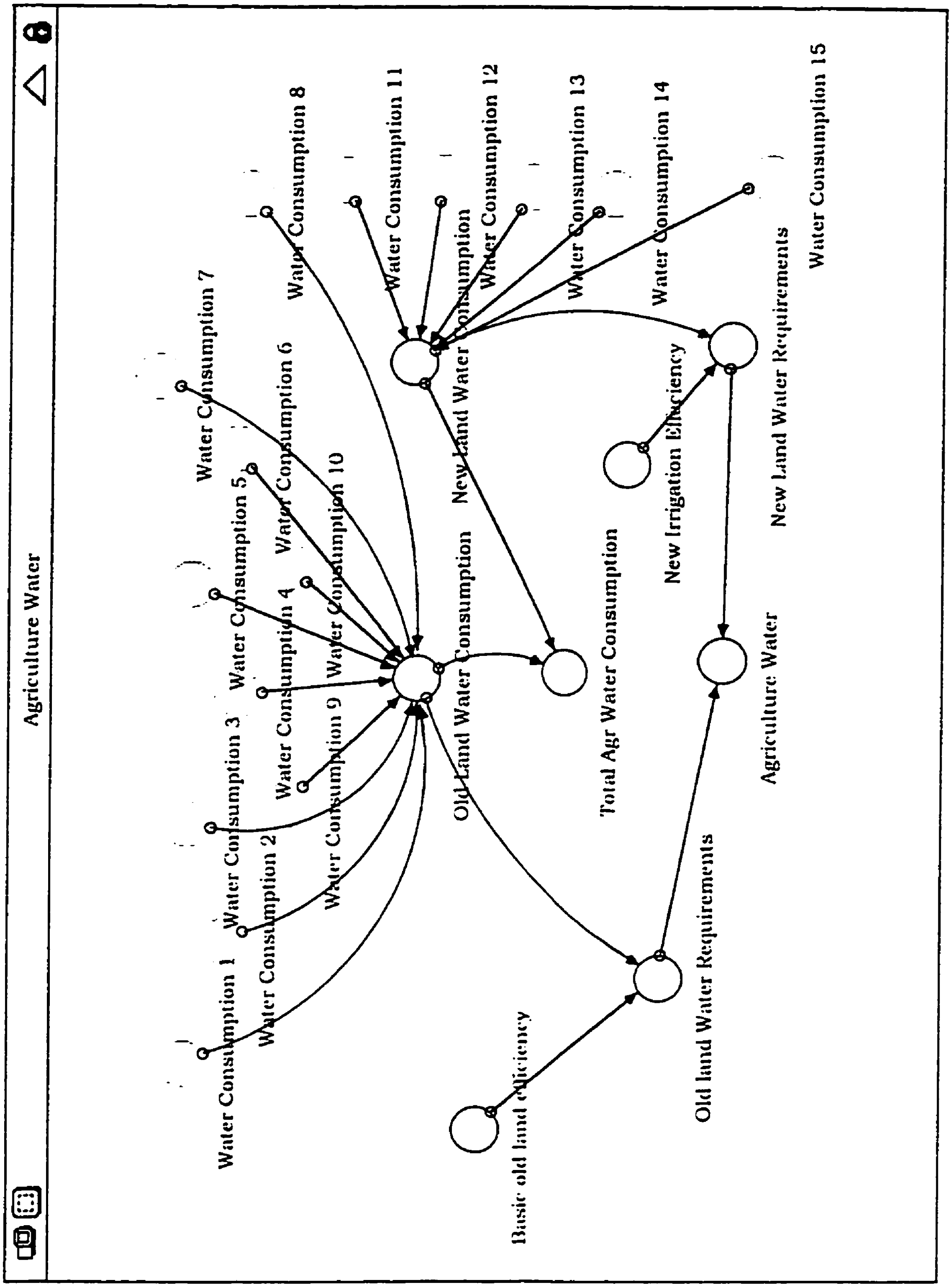


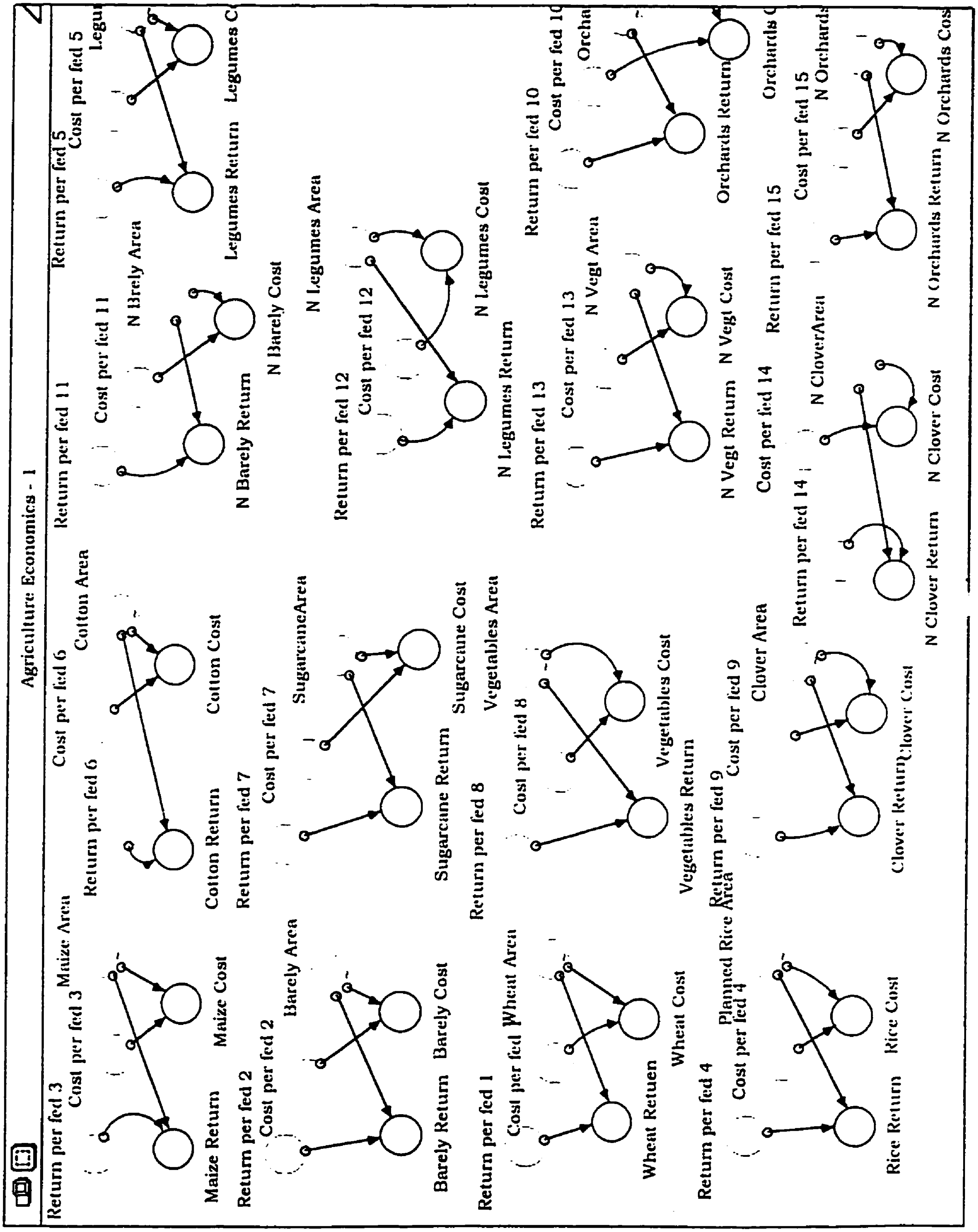
New Land
11-Barely
12-Legumes & Oily
13-VEGETABLE
14-Clover
15-ORCHAR
Total New Land
YEAR
N Barely Area
Cost per fed 11
Return per fed 11
Net Return 11
WC per fed 11
Water Consumption 11
N Legumes Area
Cost per fed 12
Return per fed 12
Net Return 12
WC per fed 12
Water Consumption 12
N Vegt Area
Cost per fed 13
Return per fed 13
Net Return 13
WC per fed 13
Water Consumption 13
N CloverArea
Cost per fed 14
Return per fed 14
Net Return 14
WC per fed 14
Water Consumption 14
N Orchards Area
Cost per fed 15
Return per fed 15
Net Return 15
WC per fed 15
Water Consumption 15

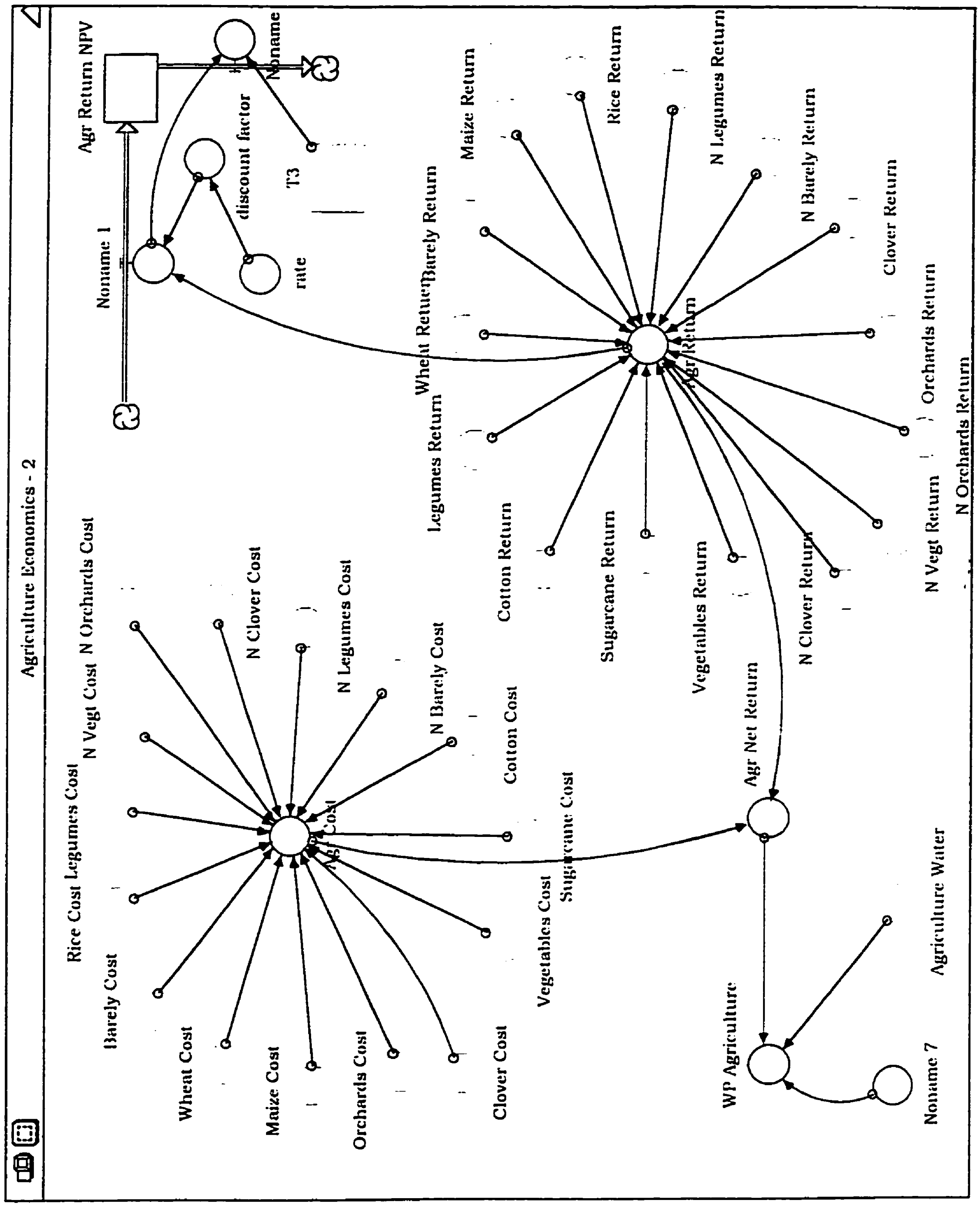


BALANCE
Resources
Balance
in
Water Balance
Demands
out
T2
T3
T1
plan
Time to develop
beep
time back
total time back
YEAR
TERMINATE


PLANS
Water Balance
DS3
DS1
time back
T3
Plan chg
PL
DP1
message
plan
Dem 1 RF
Dem 2 RF


Agriculture Water
Water Consumption 1
Water Consumption 2
Water Consumption 3
Water Consumption 4
Water Consumption 5
Water Consumption 6
Water Consumption 7
Water Consumption 8
Water Consumption 9
Water Consumption 10
Water Consumption 11
Water Consumption 12
Water Consumption 13
Water Consumption 14
Water Consumption 15
Old Land Water Consumption
New Land Water Consumption
Total Agr Water Consumption
Basic old land efficiency
Old land Water Requirements
New Irrigation Efficiency
New Land Water Requirements
Agriculture Water


Agriculture Economics - 1
Return per fed 3
Cost per fed 3
Maize Area
Maize Return
Maize Cost
Return per fed 2
Cost per fed 2
Barely Area
Barely Return
Barely Cost
Return per fed 1
Cost per fed 1
Wheat Area
Wheat Retuen
Wheat Cost
Return per fed 4
Cost per fed 4
Planned Rice Area
Rice Return
Rice Cost
Return per fed 6
Cost per fed 6
Cotton Area
Cotton Return
Cotton Cost
Return per fed 7
Cost per fed 7
SugarcaneArea
Sugarcane Return
Sugarcane Cost
Return per fed 8
Cost per fed 8
Vegetables Area
Vegetables Return
Vegetables Cost
Return per fed 9
Cost per fed 9
Clover Area
Clover Return
Clover Cost
Return per fed 11
Cost per fed 11
N Brely Area
N Barely Return
N Barely Cost
Return per fed 12
Cost per fed 12
N Legumes Area
N Legumes Return
N Legumes Cost
Return per fed 13
Cost per fed 13
N Vegt Area
N Vegt Return
N Vegt Cost
Return per fed 14
Cost per fed 14
N CloverArea
N Clover Return
N Clover Cost
Return per fed 5
Cost per fed 5
Legumes Return
Return per fed 10
Orchards Return
Return per fed 15
Cost per fed 15
N Orchards Return


Agriculture Economics - 2
Agr Return NPV
Noname
discount factor
T3
Noname 1
rate
Maize Return
Rice Return
N Legumes Return
N Barely Return
Clover Return
Barely Return
Wheat Return
Orchards Return
N Orchards Return
Legumes Return
Cotton Return
Sugarcane Return
Vegetables Return
N Clover Return
N Vegt Return
Agr Return
Agr Net Return
Agriculture Water
WP Agriculture
Noname 7
N Vegt Cost
N Orchards Cost
N Clover Cost
N Legumes Cost
N Barely Cost
Cotton Cost
Sugarcane Cost
Vegetables Cost
Rice Cost
Legumes Cost
Barely Cost
Wheat Cost
Maize Cost
Orchards Cost
Clover Cost
Agr Cost

APPENDIX 3

CASE STUDY MODEL CODE

Agriculture 1

- Cost_per_fed_1 = 435.9
  DOCUMENT: Cultivation cost per feddan of wheat
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_2 = 309.6
  DOCUMENT: Cultivation cost per feddan of barely
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_3 = 461.5
  DOCUMENT: Cultivation cost per feddan of maize and corn
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_4 = 564.6
  DOCUMENT: Cultivation cost per feddan of rice
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_5 = 392.6
  DOCUMENT: Cultivation cost per feddan of legumes and oily
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Net_Return_1 = Wheat_Area*(Return_per_fed_1-Cost_per_fed_1)
  DOCUMENT: Economic net return for wheat
  Unit: L.E

- Net_Return_2 = Barely_Area*(Return_per_fed_2-Cost_per_fed_2)
  DOCUMENT: Economic net return for barely
  Unit: L.E

- Net_Return_3 = Maize_Area*(Return_per_fed_3-Cost_per_fed_3)
  DOCUMENT: Economic net return for maize and corn
  Unit: L.E

- Net_Return_4 = Rice_Area*(Return_per_fed_4-Cost_per_fed_4)
  DOCUMENT: Economic net return for rice
  Unit: L.E

- Net_Return_5 = Legumes_Area*(Return_per_fed_5-Cost_per_fed_5)
  DOCUMENT: Economic net return for legumes and oily
  Unit: L.E

- Return_per_fed_1 = 906.7
  DOCUMENT: economic return for feddan of wheat
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_2 = 636
  DOCUMENT: economic return for feddan of barely
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_3 = 748.7
  DOCUMENT: economic return for feddan of maize and corn
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_4 = 732.7
  DOCUMENT: economic return for feddan of rice
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_5 = 898.2
  DOCUMENT: economic return for feddan of legumes and oily
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Rice_Area = if PL>4.9 then 750000 else Planned_Rice_Area
- Water_Consumption_1 = Wheat_Area*WC_per_fed_1
  DOCUMENT: Total Crop Evapotranspiration
  Unit: CUM

- Water_Consumption_2 = Barely_Area*WC_per_fed_2
  DOCUMENT: Total Crop Evapotranspiration
  unit: CUM

○ Water_Consumption_3 = Maize_Area*WC_per_fed_3
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_4 = Rice_Area*WC_per_fed_4
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_5 = Legumes_Area*WC_per_fed_5
DOCUMENT: Total Crop Evapotranspiration
CUM

○ WC_per_fed_1 = 1821
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_2 = 1608
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_3 = 2546
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_4 = 4691
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_5 = 1076
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

⊘ Barely_Area = GRAPH(YEAR)
(0.00, 124599), (5.00, 124599), (10.0, 124599), (15.0, 124599), (20.0, 124599), (25.0, 124599), (30.0, 124599)
DOCUMENT: Cultivated barely area
unit:Feddan
Policy variable

⊘ Legumes_Area = GRAPH(YEAR)
(0.00, 702918), (5.00, 702918), (10.0, 702918), (15.0, 702918), (20.0, 702918), (25.0, 702918), (30.0, 702918)
DOCUMENT: Cultivated legumes and oily area
unit: Feddan
Policy variable

⊘ Maize_Area = GRAPH(YEAR)
(0.00, 2.2e+006), (5.00, 2.2e+006), (10.0, 2.2e+006), (15.0, 2.2e+006), (20.0, 2.2e+006), (25.0, 2.2e+006), (30.0, 2.2e+006)
DOCUMENT: Cultivated maize area
unit: Feddan
Policy variable

⊘ Planned_Rice_Area = GRAPH(YEAR)
(0.00, 923971), (5.00, 923971), (10.0, 923971), (15.0, 923971), (20.0, 923971), (25.0, 923971), (30.0, 923971)
DOCUMENT: Cultivated Rice area
unit: Feddan
Policy variable

⊘ Wheat_Area = GRAPH(YEAR)
(0.00, 1.2e+006), (5.00, 1.2e+006), (10.0, 1.2e+006), (15.0, 1.2e+006), (20.0, 1.2e+006), (25.0, 1.2e+006), (30.0, 1.2e+006)
DOCUMENT: Cultivated wheat area
unit: Feddan
Policy variable

Agriculture 2

- Cost_per_fed_10 = 0
  DOCUMENT: Cultivation cost per feddan of orchards
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at govemrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_6 = 799.3
  DOCUMENT: Cultivation cost per feddan of cotton
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at govemrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_7 = 1135.9
  DOCUMENT: Cultivation cost per feddan of sugarcane
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at govemrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_8 = 747.5
  DOCUMENT: Cultivation cost per feddan of vegetables
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at govemrate level", Agr Research Center, MOA, 1993

- Cost_per_fed_9 = 0
  DOCUMENT: Cultivation cost per feddan of clover
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at govemrate level", Agr Research Center, MOA, 1993

- Net_Return_10 = Orchards_Area*(Return_per_fed_10-Cost_per_fed_10)
  DOCUMENT: Economic net return for orchards
  Unit: L.E

- Net_Return_6 = Cotton_Area*(Return_per_fed_6-Cost_per_fed_6)
  DOCUMENT: Economic net return for cotton
  Unit: L.E

- Net_Return_7 = SugarcaneArea*(Return_per_fed_7-Cost_per_fed_7)
  DOCUMENT: Economic net return for sugarcane
  Unit: L.E

- Net_Return_8 = Vegetables_Area*(Return_per_fed_8-Cost_per_fed_8)
  DOCUMENT: Economic net return for rice
  Unit: L.E

○ Net_Return_9 = Clover_Area*(Return_per_fed_9-Cost_per_fed_9)
DOCUMENT: Economic net return for clover
Unit: L.E

○ Return_per_fed_10 = 3148.2
DOCUMENT: economic return for feddan of orchards
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

○ Return_per_fed_6 = 980.7
DOCUMENT: economic return for feddan of cotton
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

○ Return_per_fed_7 = 1860
DOCUMENT: economic return for feddan of sugarcane
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

○ Return_per_fed_8 = 1994.4
DOCUMENT: economic return for feddan of vegetables
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

○ Return_per_fed_9 = 777
DOCUMENT: economic return for feddan of clover
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

○ Water_Consumption_10 = Orchards_Area*WC_per_fed_10
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_6 = Cotton_Area*WC_per_fed_6
DOCUMENT: Total Crop Evapotranspiration
CUM

○ Water_Consumption_7 = SugarcaneArea*WC_per_fed_7
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_8 = Vegetables_Area*WC_per_fed_8
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_9 = Clover_Area*WC_per_fed_9
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ WC_per_fed_10 = 4162
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_6 = 3080
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_7 = 8721
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_8 = 1705
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_9 = 1797
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

⊘ Clover_Area = GRAPH(YEAR)
(0.00, 3e+006), (5.00, 3e+006), (10.0, 3e+006), (15.0, 3e+006), (20.0, 3e+006), (25.0, 3e+006), (30.0, 3e+006)
DOCUMENT: Cultivated clover area
unit:Feddan
Policy variable

⊘ Cotton_Area = GRAPH(YEAR)
(0.00, 1.1e+006), (5.00, 1.1e+006), (10.0, 1.1e+006), (15.0, 1.1e+006), (20.0, 1.1e+006), (25.0, 1.1e+006), (30.0, 1.1e+006)
DOCUMENT: Cultivated cotton area
unit: Feddan
Policy variable

⊘ Orchards_Area = GRAPH(YEAR)
(0.00, 664471), (5.00, 664471), (10.0, 664471), (15.0, 664471), (20.0, 664471), (25.0, 664471), (30.0, 664471)
DOCUMENT: Cultivated orchards area
unit:Feddan
Policy variable

⊘ SugarcaneArea = GRAPH(YEAR)
(0.00, 250004). (5.00, 250004), (10.0, 250004), (15.0, 250004), (20.0, 250004), (25.0, 250004), (30.0, 250004)
DOCUMENT: Cultivated sugarcane area
unit:Feddan
Policy variable

⊘ Vegetables_Area = GRAPH(YEAR)
(0.00, 850468). (5.00, 850468), (10.0, 850468), (15.0, 850468), (20.0, 850468), (25.0, 850468), (30.0, 850468)
DOCUMENT: Cultivated vegetables area
unit: Feddan
Policy variable

Agriculture Economics - 1

○ Barely_Cost = Cost_per_fed_2*Barely_Area
○ Barely_Return = Return_per_fed_2*Barely_Area
○ Clover_Cost = Cost_per_fed_9*Clover_Area
○ Clover_Return = Return_per_fed_9*Clover_Area
○ Cotton_Cost = Cost_per_fed_6*Cotton_Area
○ Cotton_Return = Return_per_fed_6*Cotton_Area
○ Legumes_Cost = Cost_per_fed_5*Legumes_Area
○ Legumes_Return = Return_per_fed_5*Legumes_Area
○ Maize_Cost = Cost_per_fed_3*Maize_Area
○ Maize_Return = Return_per_fed_3*Maize_Area
○ N_Barely_Cost = Cost_per_fed_11*N_Brely_Area
○ N_Barely_Return = Return_per_fed_11*N_Brely_Area
○ N_Clover_Cost = Cost_per_fed_14*N_CloverArea
○ N_Clover_Return = Return_per_fed_14*N_CloverArea
○ N_Legumes_Cost = Cost_per_fed_12*N_Legumes_Area
○ N_Legumes_Return = N_Legumes_Area*Return_per_fed_12
○ N_Orchards_Cost = Cost_per_fed_15*N_Orchards_Area
○ N_Orchards_Return = Return_per_fed_15*N_Orchards_Area
○ N_Vegt_Cost = Cost_per_fed_13*N_Vegt_Area
○ N_Vegt_Return = N_Vegt_Area*Return_per_fed_13
○ Orchards_Cost = Cost_per_fed_10*Orchards_Area
○ Orchards_Return = Return_per_fed_10*Orchards_Area
○ Rice_Cost = Cost_per_fed_4*Planned_Rice_Area
○ Rice_Return = Return_per_fed_4*Planned_Rice_Area
○ Sugarcane_Cost = Cost_per_fed_7*SugarcaneArea
○ Sugarcane_Return = Return_per_fed_7*SugarcaneArea
○ Vegetables_Cost = Cost_per_fed_8*Vegetables_Area
○ Vegetables_Return = Return_per_fed_8*Vegetables_Area
○ Wheat_Cost = Cost_per_fed_1*Wheat_Area
○ Wheat_Retuen = Return_per_fed_1*Wheat_Area

Agriculture Economics - 2

□ Agr_Return_NPV(t) = Agr_Return_NPV(t - dt) + (Noname_1 - Noname_8) * dt
INIT Agr_Return_NPV = 0
INFLOWS:
Noname_1 = Agr_Return*discount_factor
OUTFLOWS:
Noname_8 = IF(T3>0) THEN(Noname_1) ELSE(0)

○ Agr_Cost = Barely_Cost+Clover_Cost+Cotton_Cost+Legumes_Cost+Maize_Cost+N_Barely_Cost+N_Clover_Cost+N_Legumes_Cost+N_Orchards_Cost+N_Vegt_Cost+Orchards_Cost+Rice_Cost+Sugarcane_Cost+Vegetables_Cost+Wheat_Cost
○ Agr_Net_Return = Agr_Return-Agr_Cost

- Agr_Return =
  Barely_Return+Clover_Return+Cotton_Return+Legumes_Return+Maize_Return+N_Barely_Return+N_Clover_Return+N_Legumes_Return+N_Orchards_Return+N_Vegt_Return+Orchards_Return+Rice_Return+Sugarcane_Return+Vegetables_Return+Wheat_Retuen
- discount_factor = 1/(1+rate)^(TIME-1989)
- Noname_7 = 1000000000
- rate = 0.1
- WP_Agriculture = Agr_Net_Return/(Agriculture_Water*Noname_7)

Agriculture Water

- Agriculture_Water = New_Land_Water_Requirements+Old_land_Water_Requirements
  DOCUMENT: Total agriculture water
  unit: billion CUM

- Basic_old_land_efficiency = .712
  DOCUMENT: Old land irrigation effeciency (current value)

- New_Irrigation_Effeciency = .85
  DOCUMENT: New land irrigation effeciency (Sprinkler and drip irrigation)

- New_Land_Water_Consumption =
  (Water_Consumption_11+Water_Consumption_12+Water_Consumption_13+Water_Consumption_14+Water_Consumption_15)/1E9
  DOCUMENT: Total plants evapotraspiration in new lands (consumptive use)
  unit: BCM

- New_Land_Water_Requirements = New_Land_Water_Consumption/New_Irrigation_Effeciency
  DOCUMENT: Total new land water requirement
  unit: BCM

- Old_Land_Water_Consumption =
  (Water_Consumption_1+Water_Consumption_10+Water_Consumption_2+Water_Consumption_3+Water_Consumption_4+Water_Consumption_5+Water_Consumption_6+Water_Consumption_7+Water_Consumption_8+Water_Consumption_9)/1E9
  DOCUMENT: Total plants evapotraspiration in old lands (consumptive use)
  unit: BCM

○ Old_land_Water_Requirements = Old_Land_Water_Consumption/Basic_old_land_efficiency
DOCUMENT: Old land water requirement
unit: BCM

○ Total_Agr_Water_Consumption = (New_Land_Water_Consumption+Old_Land_Water_Consumption)
DOCUMENT: Total plants evapotraspiration in old and new lands (consumptive use)
unit: BCM

BALANCE

□ T3(t) = T3(t - dt) + (T1 - T2) * dt
INIT T3 = 0
INFLOWS:
T1 = if (plan>0) then (Time_to_develop+1) else 0
OUTFLOWS:
T2 = 1

□ total_time_back(t) = total_time_back(t - dt) + (time_back) * dt
INIT total_time_back = 0
INFLOWS:
time_back = IF (Time_to_develop>0) then (Time_to_develop+3) else 0

□ Water_Balance(t) = Water_Balance(t - dt) + (in - out - Balance) * dt
INIT Water_Balance = 0
INFLOWS:
in = Resources
OUTFLOWS:
out = Demands
Balance = Water_Balance

○ beep = if time_back>0 then SOUND(1) else 0
○ TERMINATE = if YEAR>=30 then 1 else 0
○ YEAR = ROUND(TIME-total_time_back)
○ Time_to_develop = GRAPH(plan)
(0.00, 0.00), (1.00, 3.00), (2.00, 2.00), (3.00, 2.00), (4.00, 2.00), (5.00, 0.00), (6.00, 0.00)

DEMANDS

□ D3(t) = D3(t - dt) + (DM_1_RED - RF_1_INC) * dt
INIT D3 = 0
INFLOWS:
DM_1_RED = IF PLAN=4 THEN Irrigation_Eff_Increase ELSE 0
OUTFLOWS:
RF_1_INC = D3/T3

☐ D4(t) = D4(t - dt) + (DM_2_RED - RF_2_INC) * dt
INIT D4 = 0
INFLOWS:
DM_2_RED = IF PLAN=3 THEN Other_Demands_RF ELSE 0
OUTFLOWS:
RF_2_INC = D4/T3

☐ DM_1_RF(t) = DM_1_RF(t - dt) + (RF_1_INC) * dt
INIT DM_1_RF = 0
INFLOWS:
RF_1_INC = D3/T3

☐ DM_2_RF(t) = DM_2_RF(t - dt) + (RF_2_INC) * dt
INIT DM_2_RF = 0
INFLOWS:
RF_2_INC = D4/T3

○ Demands =
Other_Demands*(1+Other_Demands_Inc)*(1-DM_2_RF)+New_Land_Water_Requirements+Old_Land_Water_Consumption/Old_Land_Efficiency

○ Irrigation_Eff_Increase = 0.1

○ Old_Land_Efficiency = DM_1_RF+Basic_old_land_efficiency

○ Other_Demands_Inc = 0

○ Other_Demands_RF = .1

⊘ Other_Demands = GRAPH(YEAR)
(1.00, 7.57), (2.00, 7.86), (3.00, 8.16), (4.00, 8.46), (5.00, 8.76), (6.00, 9.06), (7.00, 9.37), (8.00, 9.67), (9.00, 9.98), (10.0, 10.3), (11.0, 10.6), (12.0, 10.9), (13.0, 11.2), (14.0, 11.5), (15.0, 11.9), (16.0, 12.2), (17.0, 12.5), (18.0, 12.8), (19.0, 13.2), (20.0, 13.5), (21.0, 13.8), (22.0, 14.1), (23.0, 14.5), (24.0, 14.8), (25.0, 15.2), (26.0, 15.5), (27.0, 15.8), (28.0, 16.2), (29.0, 16.5), (30.0, 16.5)

HAD

☐ HAD_Lake(t) = HAD_Lake(t - dt) + (Nile_Inflow + UNP - losses - HAD_Release - Spillage - Bank_Storage) * dt
INIT HAD_Lake = 50
INFLOWS:
Nile_Inflow = GRAPH(YEAR)
(1.00, 87.1), (2.00, 70.3), (3.00, 90.7), (4.00, 72.7), (5.00, 75.5), (6.00, 77.4), (7.00, 80.8), (8.00, 56.1), (9.00, 67.7), (10.0, 85.4), (11.0, 97.6), (12.0, 69.9), (13.0, 73.5), (14.0, 71.8), (15.0, 58.1), (16.0, 66.5), (17.0, 68.5), (18.0, 52.2), (19.0, 54.5), (20.0, 41.2), (21.0, 53.1), (22.0, 80.6), (23.0, 74.2), (24.0, 68.1), (25.0, 112), (26.0, 84.0), (27.0, 73.8), (28.0, 59.5), (29.0, 66.0), (30.0, 55.0)
UNP = Nile_add
OUTFLOWS:
losses = Surface_Area*2.7E-3+Seepage
HAD_Release = 55.5+Nile_add

Spillage =
IF(HAD_Lake+Nile_Inflow-HAD_Release-losses>Max_Capacity)THEN((HAD_Lake+Nile_Inflow-HAD_Release-losses-Max_Capacity)) ELSE(0)

Bank_Storage =
IF(Surface_Area>Ar)THEN(A*1E-3*(Surface_Area-Ar)*(Elevation-126)*(1+EXP(-TIME/46)))ELSE IF(Surface_Area<Ar)THEN(B*1E-3*(Ar-Surface_Area)*(Elevation-el)) ELSE(0)

A = .06
Ar = DELAY(Surface_Area,1)
B = 5.77
el = DELAY(Elevation,1)
Elevation = 79.9734+.0369801*HAD_Lake+18.8705*LOGN(HAD_Lake)
Max_Capacity = 162
Seepage = 0.038E-3*(Elevation-110)
Surface_Area = -3164.28+25.4914*HAD_Lake+1092.92*LOGN(HAD_Lake)

New Land

Cost_per_fed_11 = 309.6
DOCUMENT: Cultivation cost per feddan of barely in new land
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

Cost_per_fed_12 = 392.6
DOCUMENT: Cultivation cost per feddan of legumes in new land
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

Cost_per_fed_13 = 747.5
DOCUMENT: Cultivation cost per feddan of vegetables in new land
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

Cost_per_fed_14 = 0
DOCUMENT: Cultivation cost per feddan ofclover in new land
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

Cost_per_fed_15 = 0
DOCUMENT: Cultivation cost per feddan of orchards in new land
Unit: L.E/Feddan
Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Net_Return_11 = N_Brely_Area*(Return_per_fed_11-Cost_per_fed_11)
  DOCUMENT: Economic net return for barely in new land
  Unit: L.E

- Net_Return_12 = N_Legumes_Area*(Return_per_fed_12-Cost_per_fed_12)
  DOCUMENT: Economic net return for legumes and oily in new land
  Unit: L.E

- Net_Return_13 = N_Vegt_Area*(Return_per_fed_13-Cost_per_fed_13)
  DOCUMENT: Economic net return for vegetables in new land
  Unit: L.E

- Net_Return_14 = N_CloverArea*(Return_per_fed_14-Cost_per_fed_14)
  DOCUMENT: Economic net return for clover in new land
  Unit: L.E

- Net_Return_15 = N_Orchards_Area*(Return_per_fed_15-Cost_per_fed_15)
  DOCUMENT: Economic net return for orchards in new land
  Unit: L.E

- N_Brely_Area = Total_New_Land*.2
  DOCUMENT: Crop distribution ratios in new land are estimated from El-Shibini et-al, "Land reclamation plans in Egypt and water requirements up to year 2012", VIII IWRA Congress proceedings, Vol. 2, Cairo, 1994.

- N_CloverArea = Total_New_Land*.5
  DOCUMENT: Crop distribution ratios in new land are estimated from El-Shibini et-al, "Land reclamation plans in Egypt and water requirements up to year 2012", VIII IWRA Congress proceedings, Vol. 2, Cairo, 1994.

- N_Legumes_Area = Total_New_Land*.3
  DOCUMENT: Crop distribution ratios in new land are estimated from El-Shibini et-al, "Land reclamation plans in Egypt and water requirements up to year 2012", VIII IWRA Congress proceedings, Vol. 2, Cairo, 1994.

- N_Orchards_Area = Total_New_Land*.3
  DOCUMENT: Crop distribution ratios in new land are estimated from El-Shibini et-al, "Land reclamation plans in Egypt and water requirements up to year 2012", VIII IWRA Congress proceedings, Vol. 2, Cairo, 1994.

- N_Vegt_Area = Total_New_Land*.4
  DOCUMENT: Crop distribution ratios in new land are estimated from El-Shibini et-al, "Land reclamation plans in Egypt and water requirements up to year 2012", VIII IWRA Congress proceedings, Vol. 2, Cairo, 1994.

- Return_per_fed_11 = 636
  DOCUMENT: economic return for feddan of barely in new land
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_12 = 898.2
  DOCUMENT: economic return for feddan of legumes and oily in new land
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_13 = 1994.4
  DOCUMENT: economic return for feddan of vegetables in new land
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_14 = 777
  DOCUMENT: economic return for feddan of clover in new land
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Return_per_fed_15 = 3148.2
  DOCUMENT: economic return for feddan of orchards in new land
  Unit: L.E/Feddan
  Source : "Agricultural income estimates at governrate level", Agr Research Center, MOA, 1993

- Water_Consumption_11 = N_Brely_Area*WC_per_fed_11
  DOCUMENT: Total Crop Evapotranspiration
  unit: CUM

- Water_Consumption_12 = N_Legumes_Area*WC_per_fed_12
  DOCUMENT: Total Crop Evapotranspiration
  unit: CUM

○ Water_Consumption_13 = N_Vegt_Area*WC_per_fed_13
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_14 = N_CloverArea*WC_per_fed_14
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ Water_Consumption_15 = N_Orchards_Area*WC_per_fed_15
DOCUMENT: Total Crop Evapotranspiration
unit: CUM

○ WC_per_fed_11 = 1608
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_12 = 1076
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_13 = 1705
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

○ WC_per_fed_14 = 2364
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

WC_per_fed_15 = 4162
DOCUMENT: CUM/Feddan
Consumptive use
Water Distribution Research Institute,NWRC, MPWWR

Total_New_Land = GRAPH(YEAR)
(0.00, 1.2e+006), (3.00, 1.2e+006), (6.00, 1.2e+006), (9.00, 1.2e+006), (12.0, 1.2e+006), (15.0, 1.2e+006), (18.0, 1.2e+006), (21.0, 1.2e+006), (24.0, 1.2e+006), (27.0, 1.2e+006), (30.0, 1.2e+006)
DOCUMENT: Total cultivated area in new land
Unit: Feddan
Policy variable

PLANS

PL(t) = PL(t - dt) + (Plan_chg) * dt
INIT PL = 0
INFLOWS:
Plan_chg = if (Water_Balance<0) AND ((T3=0) OR (time_back>0)) AND((DS1>=0) or (DS3<0)) then 1 else 0
Dem_1_RF = if PL>=3 then 0.1 else 0
Dem_2_RF = if PL>=4 then 0.1 else 0
DP1 = DELAY(PL,1)
DS1 = DELAY(Water_Balance,1)
DS3 = DELAY(Water_Balance,3)
message = if Plan_chg>0 then DP1+1 else 0
plan = if NOT(PL=DP1) then (PL) else 0

RESOURCES

Nile_add(t) = Nile_add(t - dt) + (add_to_1) * dt
INIT Nile_add = 0
INFLOWS:
add_to_1 = Nile_inc/T3
Nile_inc(t) = Nile_inc(t - dt) + (Resource_1_Development - add_to_1) * dt
INIT Nile_inc = 0
INFLOWS:
Resource_1_Development = if plan=1 then Upper_Nile_Projects else 0
OUTFLOWS:
add_to_1 = Nile_inc/T3
Other_Resources(t) = Other_Resources(t - dt) + (add_to_2) * dt
INIT Other_Resources = 3.6+4.7
INFLOWS:
add_to_2 = Res_2_inc/T3

☐ Res_2_inc(t) = Res_2_inc(t - dt) + (Resource_2_Development - add_to_2) * dt
INIT Res_2_inc = 0
INFLOWS:
Resource_2_Development = if plan =2 then Other_Res_Dev_Plan else 0
OUTFLOWS:
add_to_2 = Res_2_inc/T3

○ Nile = HAD_Release
○ Other_Res_Dev_Plan = 2
○ Resources = Other_Resources+Nile
○ Upper_Nile_Projects = 3

APPENDIX 4

DOMESTIC AND INDUSTRIAL WATER REQUIREMENTS

Scenario 1

year	industry	domestic	total SC-1
1990	4.60	2.97	**7.57**
1991	4.60	3.03	**7.63**
1992	4.60	3.10	**7.70**
1993	4.60	3.17	**7.77**
1994	4.60	3.24	**7.84**
1995	4.60	3.31	**7.91**
1996	4.60	3.39	**7.99**
1997	4.60	3.46	**8.06**
1998	4.60	3.54	**8.14**
1999	4.60	3.62	**8.22**
2000	4.60	3.70	**8.30**
2001	4.60	3.78	**8.38**
2002	4.60	3.86	**8.46**
2003	4.60	3.95	**8.55**
2004	4.60	4.04	**8.64**
2005	4.60	4.13	**8.73**
2006	4.60	4.22	**8.82**
2007	4.60	4.31	**8.91**
2008	4.60	4.41	**9.01**
2009	4.60	4.51	**9.11**
2010	4.60	4.61	**9.21**
2011	4.60	4.71	**9.31**
2012	4.60	4.81	**9.41**
2013	4.60	4.92	**9.52**
2014	4.60	5.03	**9.63**
2015	4.60	5.14	**9.74**
2016	4.60	5.26	**9.86**
2017	4.60	5.37	**9.97**
2018	4.60	5.49	**10.09**
2019	4.60	5.62	**10.22**
2020	4.60	5.74	**10.34**

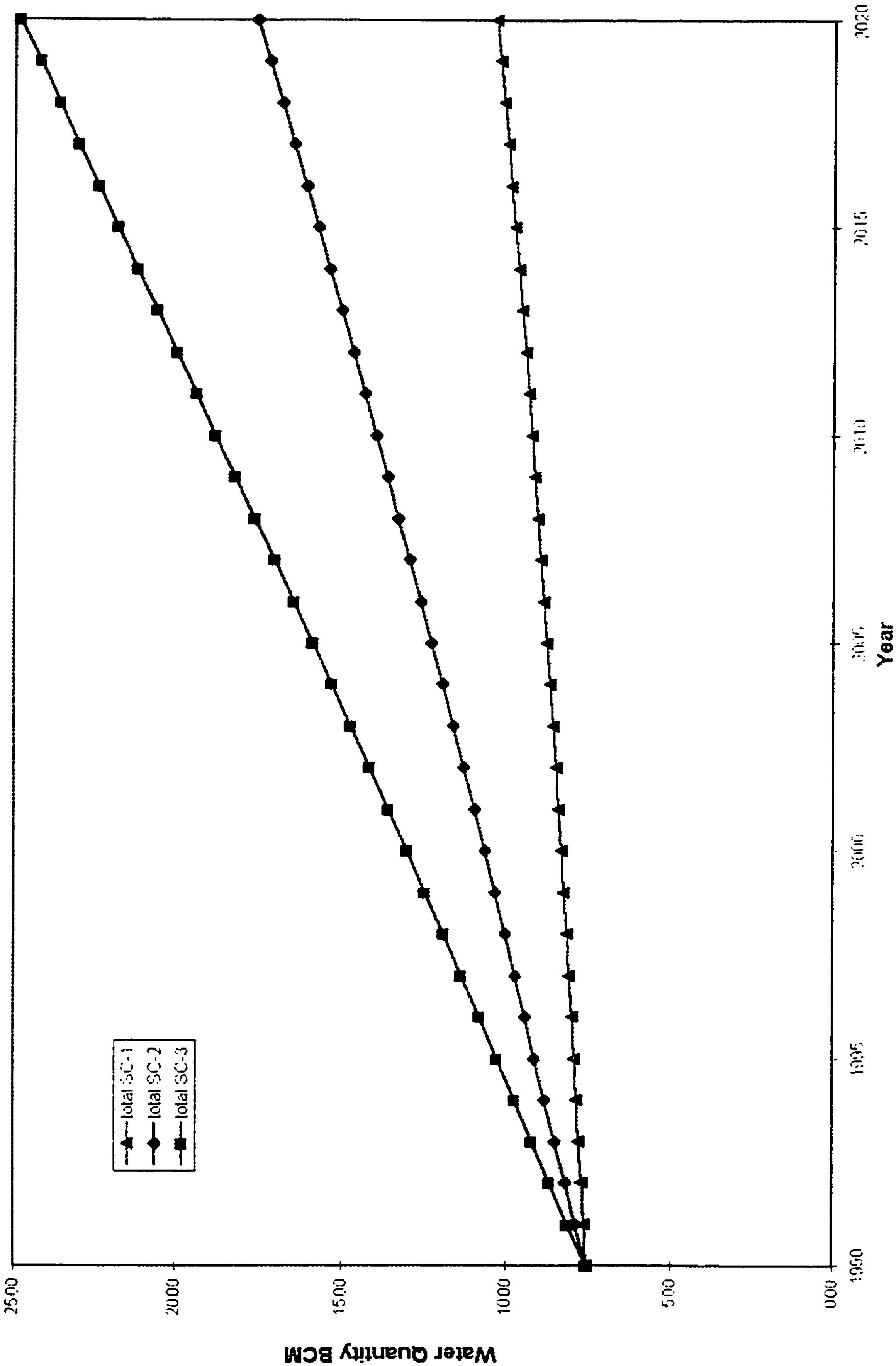
Scenario 2 & 4

year	industry	domestic	total SC-2
1990	4.60	2.97	**7.57**
1991	4.83	3.04	**7.87**
1992	5.06	3.11	**8.17**
1993	5.29	3.19	**8.48**
1994	5.52	3.27	**8.79**
1995	5.75	3.35	**9.10**
1996	5.98	3.43	**9.41**
1997	6.21	3.51	**9.72**
1998	6.44	3.60	**10.04**
1999	6.67	3.68	**10.35**
2000	6.90	3.77	**10.67**
2001	7.13	3.86	**10.99**
2002	7.36	3.96	**11.32**
2003	7.59	4.05	**11.64**
2004	7.82	4.15	**11.97**
2005	8.05	4.25	**12.30**
2006	8.28	4.36	**12.64**
2007	8.51	4.46	**12.97**
2008	8.74	4.57	**13.31**
2009	8.97	4.68	**13.65**
2010	9.20	4.80	**14.00**
2011	9.43	4.91	**14.34**
2012	9.66	5.03	**14.69**
2013	9.89	5.15	**15.04**
2014	10.12	5.28	**15.40**
2015	10.35	5.41	**15.76**
2016	10.58	5.54	**16.12**
2017	10.81	5.67	**16.48**
2018	11.04	5.81	**16.85**
2019	11.27	5.95	**17.22**
2020	11.50	6.09	**17.59**

Scenario 3

year	industry	domestic	total SC-3
1990	4.60	2.97	**7.57**
1991	5.06	3.05	**8.11**
1992	5.52	3.13	**8.65**
1993	5.98	3.21	**9.19**
1994	6.44	3.29	**9.73**
1995	6.90	3.38	**10.28**
1996	7.36	3.47	**10.83**
1997	7.82	3.56	**11.38**
1998	8.28	3.65	**11.93**
1999	8.74	3.75	**12.49**
2000	9.20	3.85	**13.05**
2001	9.66	3.95	**13.61**
2002	10.12	4.05	**14.17**
2003	10.58	4.16	**14.74**
2004	11.04	4.27	**15.31**
2005	11.50	4.38	**15.88**
2006	11.96	4.50	**16.46**
2007	12.42	4.62	**17.04**
2008	12.88	4.74	**17.62**
2009	13.34	4.86	**18.20**
2010	13.80	4.99	**18.79**
2011	14.26	5.12	**19.38**
2012	14.72	5.26	**19.98**
2013	15.18	5.40	**20.58**
2014	15.64	5.54	**21.18**
2015	16.10	5.68	**21.78**
2016	16.55	5.83	**22.38**
2017	17.01	5.99	**23.00**
2018	17.47	6.14	**23.61**
2019	17.93	6.31	**24.24**
2020	18.39	6.47	**24.86**

Total Domestic & Industrial Water Reuirements



APPENDIX 5

SCENARIO RESULTS

Scenario 1	
Year	Water Balance
1991	9.32
1992	9.32
1993	9.26
1994	9.19
1995	9.12
1996	9.05
1997	8.98
1998	8.90
1999	8.83
2000	8.75
2001	8.67
2002	8.59
2003	8.51
2004	8.43
2005	8.34
2006	8.25
2007	8.16
2008	8.07
2009	7.98
2010	7.88
2011	7.78
2012	7.68
2013	7.58
2014	7.48
2015	7.37
2016	7.26
2017	7.15
2018	7.03
2019	6.92
2020	6.80

Scenario 2	
Year	Water Balance
1991	10.64
1992	10.48
1993	10.01
1994	9.55
1995	9.12
1996	8.70
1997	8.27
1998	7.81
1999	7.35
2000	6.89
2001	6.44
2002	5.99
2003	5.54
2004	5.05
2005	4.56
2006	4.07
2007	3.59
2008	3.11
2009	2.63
2010	2.14
2011	1.65
2012	1.16
2013	0.71
2014	0.26
2015	-0.19
2016	-0.73
2012	-1.27
2013	0.71
2014	1.51
2015	2.31
2016	1.77
2017	1.23
2018	0.70
2019	0.16
2020	-0.39

Scenario 3	
Year	Water Balance
1991	10.64
1992	10.48
1993	9.77
1994	9.07
1995	8.41
1996	7.76
1997	7.09
1998	6.39
1999	5.69
2000	5.00
2001	4.30
2002	3.61
2003	2.92
2004	2.20
2005	1.46
2006	0.73
2007	0.01
2008	-0.71
2009	-1.44
2005	-2.17
2006	0.73
2007	1.26
2008	1.79
2009	1.06
2010	0.33
2011	-0.40
2012	-1.13
2007	-1.83
2008	1.79
2009	1.73
2010	1.67
2011	1.60
2012	0.87
2013	0.17
2014	-0.53
2015	-1.23
2012	-0.36
2013	1.82
2014	1.12
2015	0.42
2016	-0.36
2017	-1.14
2012	-1.92
2013	1.82
2014	2.85
2015	3.72
2016	4.40
2017	3.62
2018	2.84
2019	2.05
2020	1.26

Scenario 4	
Year	Water Balance
1991	10.64
1992	10.30
1993	9.66
1994	9.02
1995	8.48
1996	7.93
1997	7.38
1998	6.85
1999	6.32
2000	5.78
2001	5.21
2002	4.62
2003	4.03
2004	3.51
2005	3.00
2006	2.48
2007	1.90
2008	1.31
2009	0.73
2010	0.12
2011	-0.48
2012	-1.10
2008	-1.66
2009	0.73
2010	1.37
2011	2.02
2012	1.40
2013	0.84
2014	0.27
2015	-0.30
2016	-0.88
2011	-1.46
2012	1.40
2013	1.51
2014	1.60
2015	1.70
2016	1.12
2017	0.54
2018	-0.04
2019	-0.55
2016	0.58
2017	2.19
2018	1.60
2019	1.10
2020	0.58

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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