WATER RESOURCE SYSTEMS IN A REGIONAL DEVELOPMENT CONTEXT

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1. Introduction

Every development program is concerned with either improving that which has been developed or with establishing that which was not previously considered possible. In both cases an intensive structured thinking process has to precede whatever action/decision which is to be made.

Regional development is a term which embraces specific kinds of activities which, if properly carried out, would result in achieving predetermined goals. Despite many efforts to formalize the steps in the regional development process, the results obtained thus far are rather modest. There are several reasons which make this process difficult. Among them are the following: complicated structure of any system on a regional level; lack of information about the impact of a particular system's element on all other elements; connections and mutual impact of various regional systems, etc.

This paper deals with one of the most frequently encountered systems in regional development; namely, water resource systems. Water resources have always been of major importance because of their vital nature. This is why development of a water resource system has always taken place as the first stage of regional development. Furthermore, because of the long history of water resource development one might expect that everything is quite clear and the development of such types of systems is merely a technical question. Unfortunately, this is not the case. Although systems analysis has penetrated deeply into the area of water resource systems over the last 20-25 years much work remains on the structuring of these systems, i.e. extracting the main elements of any water resource system; hydrologic, economic and environmental description of the elements as well as their mutual impact. Moreover, all of the achievements in water resource systems do not seem to have been fully utilized either in systems analysis theory or in practice. In the paper, first of all, an extraction is made of all the possible elements which, hopefully, make up every water resource system. Then, those elements are described (or, for some there is only an intention to be described) in three aspects: hydrological, economical and environmental. After performing those two steps one can proceed further with generation of arbitrary systems in order to choose a particular one. Or one can imbed these elements in an existing configuration in order to understand how the system will react to any external/internal changes as well as investigate the consequences of making any decision in the system.

2. Elements of Water Resource Systems

The motivation to write this paper was found in Mario Bunge's remark [1]: "Not all things are systems but all systems are composed of things." This remark seems to be very important because--in most cases--what we are doing now in systems analysis is just the opposite, i.e., we attempt to investigate the system without knowing in detail the behavior of the composed elements. In many cases the obtained results would not be of the same value as they would be if we knew the behavior of the elements in detail. As previously mentioned, there are three major steps which precede performing systems analysis, especially in development, of a particular water resource system:

A. Can we define the basic things (elements) which make up a water resource system?

B. If so, can we describe them from different points of view, say hydrological, economical and environmental?

C. Can we compose/model a system using these basic elements and try to investigate all substantial processes in it?

Real systems analysis would begin after we have explored all answers to these questions.

Let us now try to answer all of the aforementioned questions in turn.

A. Can we define the basic elements which make up a water resource system?

Our intention is first of all to try to list all possible types of elements which can be found in water resource systems, especially in the context of systems development. This is, fortunately, not a very difficult problem because people have more or less always tried to do this. One, of all possible classifications, could be the following:

1. Reservoirs
2. Aquifers
3. Artificial lakes (incl. estuaries and bays)
4. Water ways
5. Channels
6. Pipelines
7. Nodes
8. Pumps
9. Treatment plants
10. Hydropower stations
11. Irrigation fields
12. Residential water supply
13. Industrial water supply

The elements from 1 to 9 could be defined as "supply" (or "supply supporting") elements while the rest are "demand" elements. The demand elements have many things in common as shown in Figure 1. In this Figure the DEMAND is intentionally separated from the PROCESS for the sake of modeling. Figure 1 indicates that with each process the needs of both water demand and supply alternatives are associated. All consumers produce waste water and in the case of water treatment, waste residuals are produced. Both waste water and waste residuals influence the environment. Some of the feedback from the environment to the other elements in Figure 1 are very important. Some of them do not exist for certain types of users.

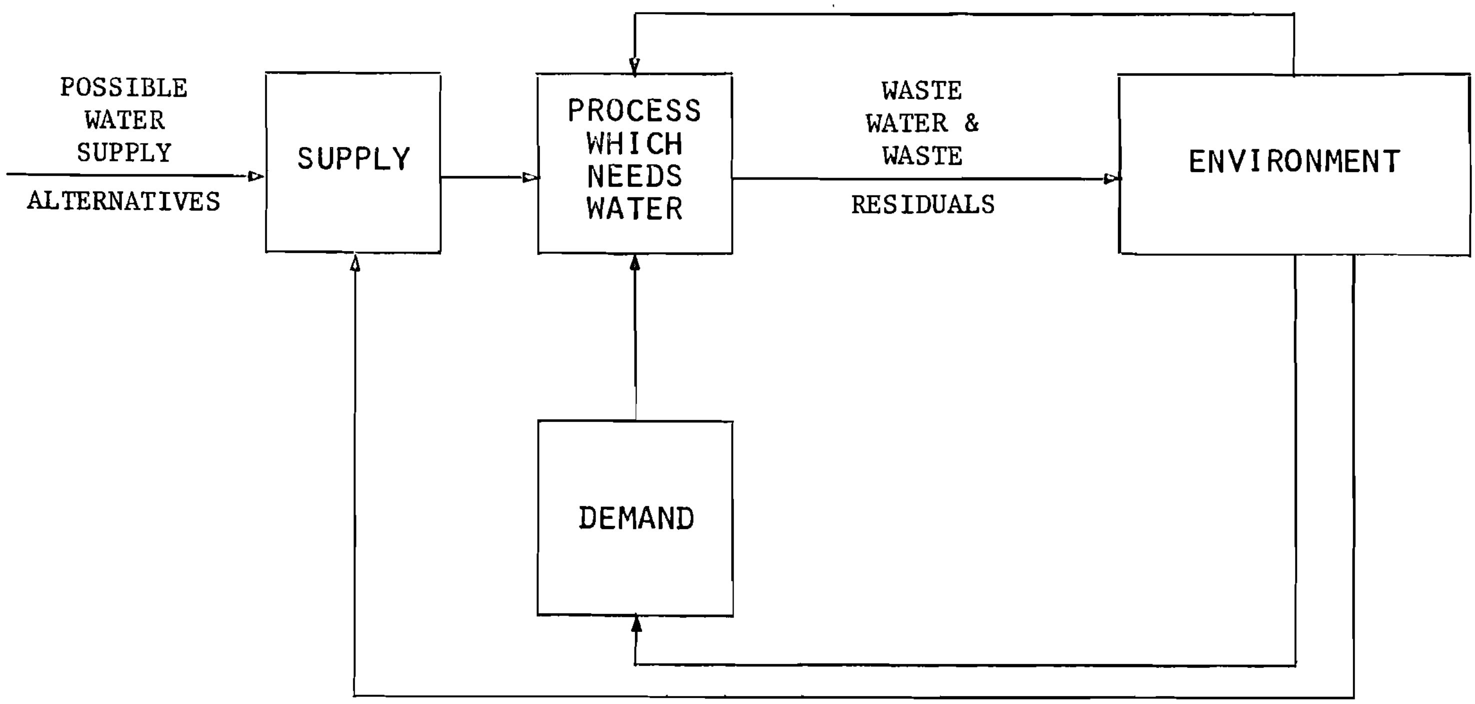


Figure 1.

The list of elements mentioned above does not pretend to be a comprehensive one. It depends rather on the context of the investigation carried out. Sometimes some of the elements overlapped (i.e. reservoirs and artificial lakes, or water ways and channels). Situations exist which elements, at first glance, seem to overlap, but those are completely different elements.

In the aforementioned list of elements less attention has been paid to non-conventional supply alternatives, i.e. desalination of saline water; precipitation augmentation; watershed management to increase runoff; water transfer from adjacent basins, etc. These were not included in the list for the following reasons:

- some of them can be taken into account through exogenous variables (for example, precipitation augmentation and watershed management will mainly influence the inflow of a reservoir);

- some of them are a combination of elements previously described (for example, water transfer is a combination of reservoirs (or nodes) outside of the region and channels (pipelines); and

- many people think that it is too early to consider these types of elements and economically disadvantageous to put them into operation.

B. Can we describe the various basic elements? In what context should they be described?

In tracing the history of water resource systems one notices that in the very beginning only pure engineering and hydrologic problems dominated. Later on, both engineering and economic problems became crucial ones in water resource development and management. Today in water resource systems not only hydrologic and economic problems are important but environmental problems should also be an indivisible part of the analysis. It is worthwhile mentioning that there have been many examples which indicate the substantial role of environmental consideration when making decisions. One should not forget that a short-term economic gain may turn into a long-term environmental loss as, for example, happened in the Tigris-Euphrates valley. Hence, we should try to describe, as comprehensively as possible, each of the thirteen elements before imbedding them in a particular water resource system.

The following characteristics seem quite appropriate: hydrologic, economic and environmental. Each of these characteristics is represented by the input of the element, output and state variables as follows:

input hydrological variables (IH)
input economic variables (IE)
input environmental variables (IN)

output hydrologic variables (OH)
output economic variables (OE)
output environmental variables (ON)

state hydrologic variables (SH)
state economic variables (SE)
state environmental variables (SN).

It should be mentioned that a basic input-output description of the elements was used because of the following reason. When one applies systems analysis to a concrete system the most important thing to be investigated is the relationship between/and impacts on various systems elements. Those relationships and impacts manifest themselves through input and output variables.

In this paper there is no attempt to identify all of the variables which are important for regional water resource development as well as all models presently under development. Rather, we have outlined some questions which could be developed at a later time if the methodology proposed in the paper seems appropriate.

Let us now consider the characteristics of the three basic elements in turn.

2.1 Hydrologic Characteristics of the Basic Elements

The input-output variables can be easily identified. These are usually inflows in and outflows from a particular element. Although there are many models, in particular for inflow prediction, they need to be refined, especially for the purpose of regional development. Special attention should be paid to the collection and development of models with long-term forecasting possibilities.

State variables in the hydrologic description of the basic elements appear when the time, or a given function of space, are involved explicitly in the analysis. They indicate, for instance, the amount of water available at a particular point of time in the k^{th} element. For some of the elements, such as pumps, various kinds of users, etc., the concept of state either can not be defined or there is no need for a definition.

The model to be developed (or to be chosen among the existing models) for any particular element should link the input, output and/or state variables. In Table 1 these models have only been sketched without specifying their explicit form. It should be mentioned, however, that these models as well as the models describing economic and environmental characteristics do not always need to be quantitative models.

2.2 Economic Characteristics of the Basic Elements

The economic consequences of building an element in the system are quite different for the various elements. Nevertheless, there are a certain number of input characteristics common to all elements. As such, one can consider the following variables:

- construction - raw/man-made materials;
- energy;
- land and forest use;
- manpower.

In addition to these input variables one can add others, specific to particular element variables which are pertinent to the purpose of the analysis.

As an output of economic variables people usually utilize the concept of profit, improvement of national or regional welfare, enhancement of the environmental quality, etc. For supply supporting elements the profit manifests itself by the elements which demand water.

State variables can appear in the time pattern of development representing especially the extent of development of a particular element. In other cases as a state variable one can use the accumulated amount of profit, welfare, etc. over a given time horizon.

2.3 Environmental Characteristics of the Basic Elements

As mentioned in the Introduction, the environmental characteristics of the basic elements and the system composed of those elements will have a large impact on the decisions made in any given water resource system. In other words, as P.C. Gardiner and W. Edwards [2] have mentioned "...builders, in the limit, want to build and develop everywhere; the environmentalists, in the limit, oppose any building and development anywhere." It is quite clear of course, that development cannot be stopped. The question is how to limit the undesired consequences of this development. These social attitudes towards development are very important but we will consider them at a later time when the entire system is analyzed. For the present we will concentrate on an environmental description of the basic elements.

Unlike hydrologic and economic characteristics, environmental characteristics vary substantially from one element to another. In particular, this concerns input variables as shown in Table 1. The output characteristics are usually concerned with some quality of the environment including water quality, physical and biological conditions as well as aesthetics and human and cultural interests. As state environmental variables one can identify the evolution of certain variables.

We would like to stress once again that the things which have been described in Table 1 are neither a comprehensive list of input/output variables nor actual models. There is still much work to be done in order to systematize the experience in this field. This kind of activity would also recognize certain gaps in our knowledge and would stimulate further research in this direction. But one thing is rather clear. One cannot produce a sound systems analysis if the description of the basic elements which compose any system is flawed.

3. Synthesis of Water Resource Systems By Using Basic Elements

A description of the basic elements can be characterized as a pre-systems analysis. The real systems analysis would begin with exploring various questions of the following type. After describing all of the characteristics of the basic elements, can we describe and analyze the behavior of a proposed water resource system or can we imbed those elements in a particular existing system? Can we predict the future behavior of the system from hydrological, economical and environmental points of view? How will the system react if we change its structure through imbedding/taking out elements? What overall impact will the system have on other interacting systems, and the like?

The answer to these questions is of vital importance for people responsible for making decisions. We do not believe that these people can be supplied with universal tools which can solve whatever problems which arise in water resource systems. Rather, we believe that DM's could be supplied with a flexible model which can easily absorb changes and can produce a spectrum of decisions for analysis before one of them is implemented.

Regional water resource development has always been necessary in order to achieve certain objectives. Improvement in the national or regional welfare is usually the basic motivitation for developing water and related resources. Because welfare is a rather ambiguous term other objectives have been developed. As mentioned in [3] "...the following five objectives are normally most appropriate to resource development:

1. Increasing national income (augmenting aggregate consumption.

2. Promotion of national autonomy of self-sufficiency. This includes, for example, maximizing economic surplus or exports from project gains.

3. Redistribution of consumption. This usually means directing the increments provided by growth from the project to backward regions, low-income groups, or sectors.

4. Preservation of the quality of the environment.

5. Fulfilling 'merit wants.' These apply, for example, to the enhancement of historic, cultural and scenic monuments and sites."

It should be pointed out that these objectives are quite general and hence, they can be achieved in vast structures of systems. In many cases this will be an advantage rather than an obstacle because several variants may be compared.

The <u>second step</u>--after setting up and clarifying the objectives--is to define in more detail the subgoals to be achieved. As examples of such goals one can think about producing a specific bill of goods--industrial, agricultural, etc., power generation, water supply of populated areas, more detailed measures to preserve the quality of the environment, and so forth.

The third step is--using the basic elements--to draw one possible structure of a water resource system which seems to satisfy the determined overall objective and the specified subgoals. This step is still more an art than a science, i.e. there is no satisfactory formal way to determine the structure of the system by only knowing the objectives.

From the point of view of systems analysis the fourth step is the most important one. Here the systems analyst builds a model which represents the behavior of the system in hydrologic, economic and environmental aspects. To analyze the system both simulation and optimization procedures can be applied.

A good compromise among fulfilment of objectives can be achieved if one applies these four steps several times.

4. Example

The methodology which has been briefly described above can be illustrated by a simple artificial example.

1. Suppose the overall objective is to increase the national income. This objective is more pertinent to developing nations and regions than to regions already developed. To achieve this objective three subgoals have been generated; namely, industrial development, agriculture, and power generation. Each of these subgoals could be achieved by building plants to produce a certain number of goods. To define these plants one may need to have an overall picture of--or just an idea about--the resources available, and in particular, water resource availability.

This step of the analysis can be carried out on a very high level in the system's development hierarchy, i.e. it does not concern only water resource development but the development of the entire region.

2. After specifying the plants which are to be developed, we should determine the quantity and quality of water needed. For this purpose the hydrologic and environmental models of the basic elements 10,11,12 and 13 as well as their demand models can be used. The concept of the WELMM approach now being developed at IIASA can also be utilized here.

3. Evaluation of possible water supply through the models predicting water inflow and ground water sources in the system (this usually has to be done at several major points). At this step water supply alternatives other than those available in the region can be considered, i.e. water interbasin transfer, desalination, etc. Also, at this stage rough estimates should be made of the amount of water to be stored in the region.

4. Matching demand with supply. This is the point to initiate an iteration starting with the first step if supply cannot be met by any available means.

5. After performing the previous step one can proceed by mapping out the structure of a water system using the basic elements. This, for example, will lead us to the structure shown in Figure 2. This structure should reflect in a proper way all hydrologic, economic and environmental relations among the basic elements as well as the system's external relations.

6. This step is one of the most important ones. Here all hydrologic, economic and environmental consequences for a given time period should be thoroughly investigated. Also, social attitudes and other relevant factors for making decisions about the proposed structure can be incorporated. This step can indicate some disadvantages of the structure considered and hence, one can return to some of the previous steps.

A model of this type would allow various evaluations to be made, for example:

1. Examination of different regional development patterns. Evaluation of water demands and supply alternatives for a certain time horizon.

2. Evaluation of water deficit/surplus at each point of the model. Application of optimization procedures for these particular cases.

3. Evaluation of different goals and plans proposed by external and internal organizations and authorities.

4. Evaluation of long-term/short-term changes on water quality and environmental quality, in particular, points in the system, and so forth.

Some of the points discussed in this example have been oversimplified, but the example itself is not meant to serve as a real case study. Rather, several guidelines have been shown which will promote further thinking and construction of models to help DM's in making decisions for real situations.

We do not suggest a formal procedure which has to be followed, by all means. The paper shows just one way of thinking which might/or might not be useful, depending on the system we are dealing with. The only thing we have insisted on throughout the paper is that structured thinking would and could help the DM's to achieve certain positive results which would not be achieved otherwise.

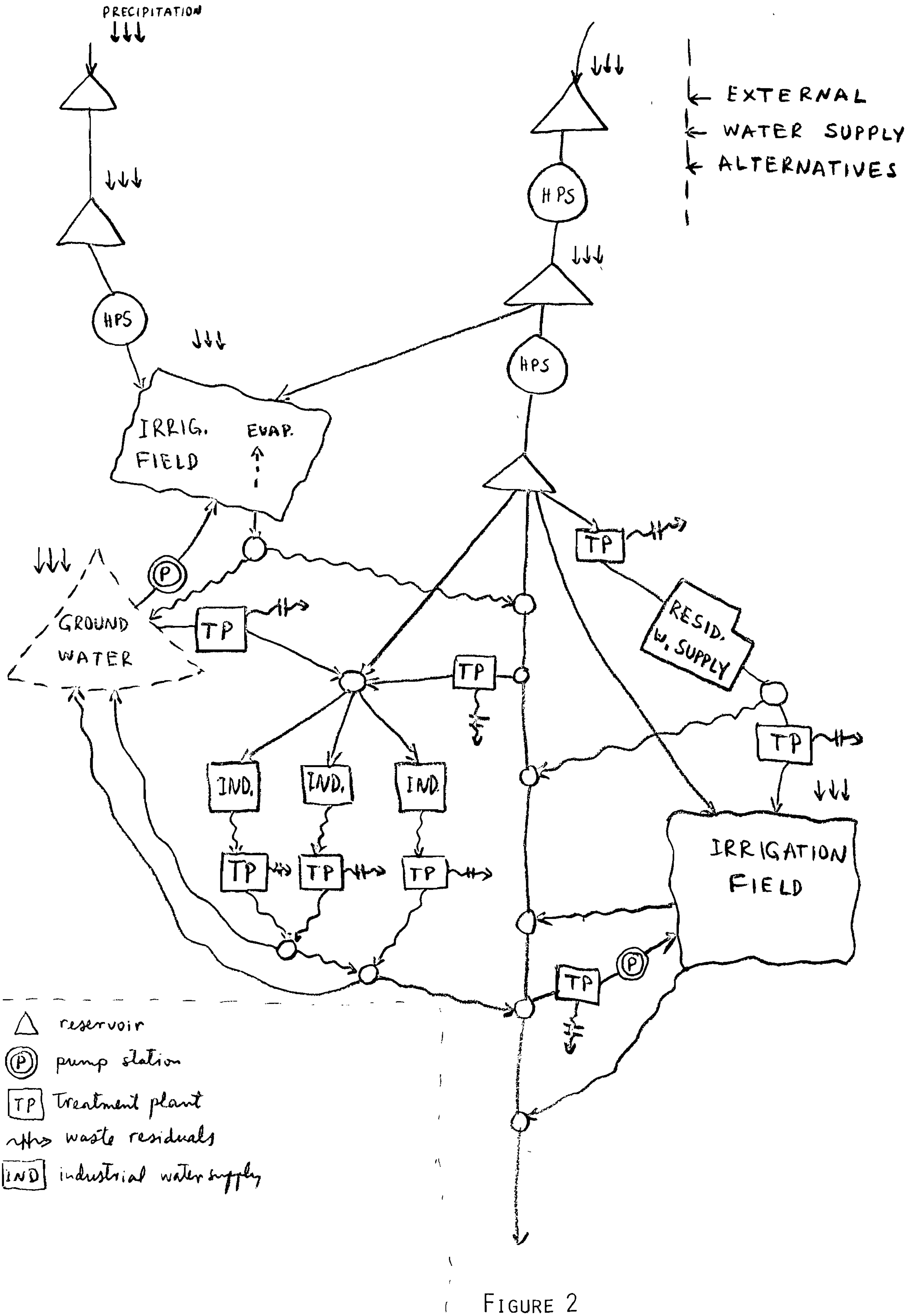

PRECIPITATION
EXTERNAL
WATER SUPPLY
ALTERNATIVES
HPS
HPS
HPS
IRRIG.
FIELD
EVAP.
P
GROUND
WATER
TP
TP
TP
RESID.
W. SUPPLY
TP
IND.
IND.
IND.
TP
TP
TP
IRRIGATION
FIELD
TP
P
reservoir
pump station
Treatment plant
waste residuals
industrial water supply

FIGURE 2

TABLE 1A

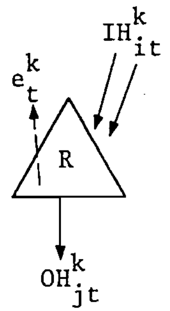
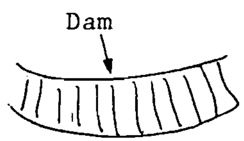
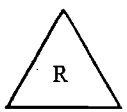
ELEMENTS RESERVOIR k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_i - i^{th} inflow (runoff, precipitation, water transfer, etc.)	OH^k_{jt} - withdrawl (for different purposes) e^k_t - evaporation's and filtration's coefficient. $0 \leq e^k_t \leq 1$	SH^k_t - amount of water in the k^{th} reservoir at time t	$SH^k_t = \begin{cases} A^k_t, \text{ if } M^k_1 \leq A^k_t \leq M^k_2 \\ M^k_1, \text{ if } A^k_t \leq M^k_1 \end{cases}$ where $A^k_t = SH^k_t = SH^k_{t-1} + \sum_i IH^k_{it} - \sum_j OH^k_{jt} - e^k_t SH^k_{t-1}$ M^k_1 - dead storage M^k_2 - capacity of the reservoir	HYDROLOGIC DESCRIPTION
	IE^k_{it} - construction materials, energy, land and forest use, manpower	OE^k_t - benefit of having the k^{th} reservoir. This is an expected future benefit which manifests itself by supplying the other elements with water.	Rate of building the k^{th} reservoir, or location of the reservoir.	$OE^k_t = f(IE^k_{it}$, profit of all elements consuming/using water)	ECONOMIC DESCRIPTION
	IN^k_{it} : SH^k_t - amount of water in the reservoir; water surface; depth; type of the soil; locations and landscape; land use pollutants.	ON^k_{jt} : Erosion; Deposion; Flora; Birds; Land animals; Forestry; Hunting; Scenic Views; Wilderness Qualities; Open Space; Parks & Reserves; Historical & Archeological Water Quality; Climate; Recreation.		$ON^k_{jt} = f(IN^k_{it}$, for all i)	ENVIRONMENTAL DESCRIPTION

TABLE 1B

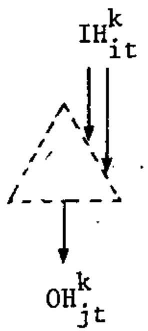
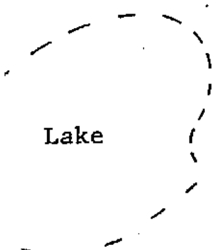
ELEMENTS AQUIFER k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_{it}: precipitation (runoff); water from industry, agriculture, residential supply, etc.	OH^k_{jt}: amount of water taken by pump stations	SH^k_t - amount of water (or <u>water level</u>) in the k^{th} aquifer at time t	$SH^k_t = SH^k_{t-1} + \sum_i IH^k_{it} - \sum_j OH^k_{jt}$	HYDROLOGIC DESCRIPTION
 drilling wells	IE^k_{it}: construction materials, energy, land and forest use, manpower for drilling and building of wells	OE^k_t - benefit of having the k^{th} well in exploration. This is an expected future benefit which manifests itself by supplying the other elements with water		$OE^k_t = f(IE^k_{it}$, all i; profit of the elements consuming/using water)	ECONOMIC DESCRIPTION
	IN^k_{it}: SH^k_t; water depth surface of water table type of rocks pollutants	ON^k_t: water quality		$ON^k_t = f(IN^k_{it}$, all i)	ENVIRONMENTAL DESCRIPTION

TABLE 1c

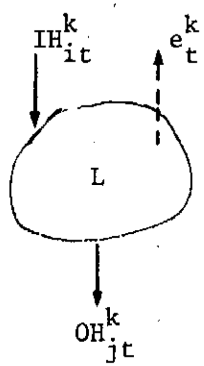
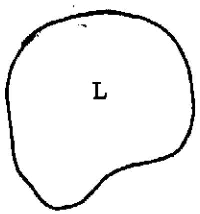
ELEMENTS NATURAL LAKE (ESTUARY BAY) k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_{it}: direct precipitation runoff inflow from industry, agriculture, residential water supply, inflow from aquifers	OH^k_{jt}: amount of water taken by: pump stations gravitation intake e^k_t: evaporation coefficient $0 \leq e^k_t \leq 1$	SH^k_t: amount of water in the k^{th} lake at time t	$SH^k_t = SH^k_{t-1} + \sum_i IH^k_{it} - \sum_j OH^k_{jt} - e^k_t SH^k_{t-1}$	HYDROLOGIC DESCRIPTION
Activities to make lake's water available to various users should be taken into account in this description	IE^k_{it}: construction materials, energy, manpower for making outlets or for cleaning bottoms and beaches to provide beneficial water use.	OE^k_t: benefit of having the k^{th} lake explored.		$OE^k_t = f(IE^k_{it}$, all i, benefit from the users)	ECONOMIC DESCRIPTION
	IN^k_{it}: SH^k_t; water depth water surface type of soil landscape pollutants	ON^k_{jt} water quality, erosion deposition, flora, birds, land animals, scenic view, wilderness qualities, open space, parks & reserves, recreation, climate		$ON^k_{jt} = f(IN^k_{it}$, all i)	ENVIRONMENTAL DESCRIPTION

TABLE 1D

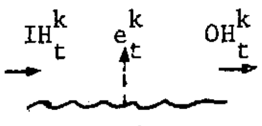
ELEMENTS CHANNEL k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_t^k: inflow in the k^{th} channel	OH_t^k: outflow from the k^{th} channel e_t^k: evaporation, filtration, coefficient $0 \le e_t^k \le 1$	SH_t^k - level of water in the k^{th} channel at time t	$OH_t^k = e_t^k \cdot IH_t^k$ $SH_t^k = SH_{t-1}^k + IH_t^k - OH_t^k - e_t^k IH_t^k$	HYDROLOGIC DESCRIPTION
Activities connected with building of the k^{th} channel	IE_{it}^k: construction materials, energy, land & forest use, manpower	OE_t^k: benefit of having the k^{th} channel		$OE_t^k = f(IE_{it}^k$, all i; benefit obtained from the users)	ECONOMIC DESCRIPTION
	IN_{it}^k: IH_t^k; water surface type of soil landscape pollutants	ON_{jt}^k erosion deposition flora birds land animals scenic view recreation activities water quality		$ON_{jt}^k = f(IN_{it}^k$, all i) Water quality in the input MAY DIFFER from the quality at the output.	ENVIRONMENTAL DESCRIPTION

TABLE 1E

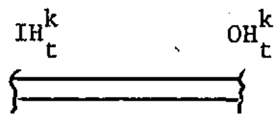
ELEMENTS PIPELINE k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_t^k: inflow in the k^{th} pipeline	OH_t^k: outflow from the k^{th} pipeline		$OH_t^k = IH_t^k$	HYDROLOGIC DESCRIPTION
Activities connected with building the k^{th} pipeline	IE_{it}^k: construction materials energy land and forest use - temporary if the pipeline is underground; otherwise permanent land use manpower	OE_t^k: benefit of having the k^{th} pipeline		$OE_t^k = f(IE_{it}^k$, all i; benefit obtained from the users)	ECONOMIC DESCRIPTION
	IN_{it}^k: IH_t^k; dimension of the pipeline	ON_{jt}^k: Scenic view; temporary land use, or permanent land use		<u>No quality problems</u> $ON_{jt}^k = f(IN_{it}^k$, all i)	ENVIRONMENTAL DESCRIPTION

TABLE 1F

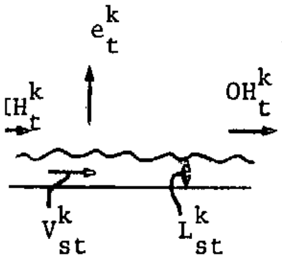
ELEMENTS WATERWAY k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_t^k: inflow in the k^{th} waterway	OH_t^k: outflow from the k^{th} waterway e_t^k - evaporation and filtration coefficient $0 \leq e_t^k \leq 1$ L_{st}^k - water level along the k^{th} waterway V_{st}^k - water velocity along the k^{th} waterway		$OH_t^k = e_t^k \cdot IH_t^k$ $L_{st}^k = f(IH_t^k)$	HYDROLOGIC DESCRIPTION
ctivities connected ith building (or aking usable) the th waterway	IE_{it}^k: construction materials energy land and forest use manpower	OE_t^k: benefit of having the k^{th} waterway		$OE_t^k = f(IE_i^k$, all i; benefit obtained by the users)	ECONOMIC DESCRIPTION
	IN_{it}: IH_t^k, water surface, type of soil, landscape, number of vehicles passing the k^{th} waterway at time t	ON_{jt}^k: erosion, deposition, flora, birds, land animals, scenic view, recreation activities, water quality		$ON_{jt}^k = f(IN_{it}^k$, all i) Input water quality <u>IS BETTER</u> than output water quality.	ENVIRONMENTAL DESCRIPTION

TABLE 1G

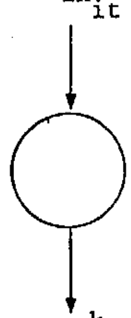
ELEMENTS NODE k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
IH^k_{it}  OH^k_{jt}	IH^k_{it}: inputs from other elements	OH^k_{jt}: outputs to other elements		$\sum_i IH^k_{it} = \sum_k OH^k_{jt}$	HYDROLOGIC DESCRIPTION
f the node is a atural one, then no conomic description. n the case of the rtificial node, the conomic description epresents the activi- ies connected with uilding the k^{th} node	IE^k_{it}: construction materials energy land use manpower	No direct benefit OE^k_t: Aesthetic consideration could be associated, i.e. as an output we have environmental description.		$OE^k_t = f(IE^k_{it}, \text{all } i)$	ECONOMIC DESCRIPTION
ombined with economic escription					ENVIRONMENTAL DESCRIPTION

TABLE 1H

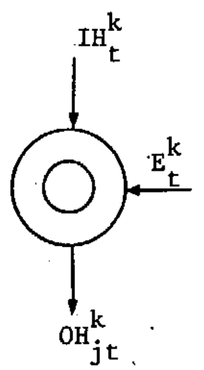
ELEMENTS: PUMP STATION k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_t^k: amount of pumped water E_t^k: energy demand for pumping water	OH_{jt}^k: amount of water delivered to other elements		$IH_t^k = \sum_k OH_{jt}^k$ $E_t^k = f(IH_t^k)$	HYDROLOGIC DESCRIPTION
Activities concerned with building pump station	IE_{it}^k: construction materials energy land use manpower	OE_t^k: benefit of having the k^{th} pump station		$OE_t^k = f(IE_{it}^k$, all i; $E_t^k)$	ECONOMIC DESCRIPTION
	No Environmental Influence (Land use can be neglected in most of the real cases)				ENVIRONMENTAL DESCRIPTION

TABLE 11

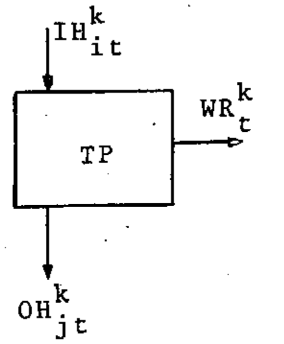
ELEMENTS TREATMENT PLANT k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_{it}: amount of waste water from different sources	OH^k_{jt}: amount of treated water to be delivered to other elements WR^k_t: waste residuals to be disposed of somewhere in the region		$\sum_j OH^k_{jt} = K^k \sum_i I^k_{it}$ $0 < K^k < 1$	HYDROLOGIC DESCRIPTION
conomic activities oncerned with build- ng the k^{th} plants	IE^i_{it}: construction materials energy land use manpower	OE^k_t: benefit of having the k^{th} treatment plant		$OE^k_t = f(IE^k_{it},\ \text{all } i)$	ECONOMIC DESCRIPTION
	IN^k_{it}: WR^k_t land use transportation, etc.	ON^k_{jt} various environmental effects		$ON^k_{jt} = f(IN^k_{it},\ \text{all } i)$ Connection between input and output quality	ENVIRONMENTAL DESCRIPTION

TABLE 1J

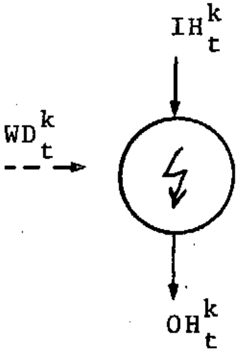
ELEMENTS HYDROPOWER STATION k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_t^k: input amount of water WD_t^k - water demand (obtained as an output from DEMAND MODEL which is not discussed here)	OH_t^k: output amount of water E_t^k -amount of energy produced		$OH_t^k = IH_t^k = a_t^k \cdot WD_t^k$ $0 \leq a_t^k \leq 1$ $E_t^k = f(IH_t^k)$	HYDROLOGIC DESCRIPTION
Economic activities concerned with building the k^{th} hydropower station	IE_{it}^k: construction materials energy consumed for building manpower E_t^k - energy produced	OE_t^k: benefit obtained by having the k^{th} hydropower station		$OE_t^k = f(IE_{it}^k, \text{ all } i)$	ECONOMIC DESCRIPTION
	No Environmental Consequences (except for aesthetic considerations)				ENVIRONMENTAL DESCRIPTION

TABLE 1K

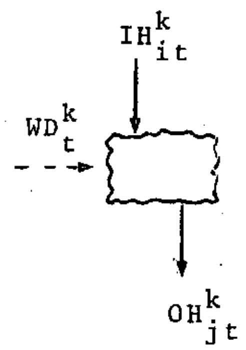
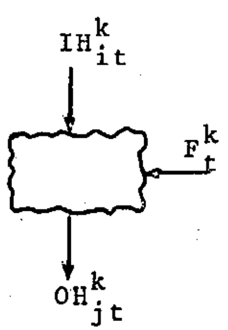
ELEMENTS IRRIGATION FIELD k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_{it}: - precipitation - water delivered to the k^{th} field from other water sources WD^k_t - water demand (obtained as an output from DEMAND MODEL which is not discussed here)	OH^k_{jt}: - amount of water going out of the k^{th} field, i.e. either to the river or to recharge aquifers - evapotranspiration from the k^{th} field		$\sum_j OH^k_{jt} = \sum IH^k_{it}$; $\sum_i IH^k_{it} = a^k_t WD^k_t$ $0 \le a^k_t \le 1$	HYDROLOGIC DESCRIPTION
Economical activity concerned with building an irrigation network as well as the benefit from crops being grown on the field	IE^k_{it}: construction materials energy land use manpower fertilizers IH^k_{it} type of irrigation	OE^k_t benefit obtained by having the k^{th} irrigation field		$OE^k_t = f(IE^k_{it}, \text{ all } i)$	ECONOMIC DESCRIPTION
	IN^k_{it}: IH^k_{it} F^k_t type of soil	ON^k_t: output water quality		$ON^k_t = f(IH^k_{it}, F^k_t, \text{type of soil})$	ENVIRONMENTAL DESCRIPTION

TABLE 1L

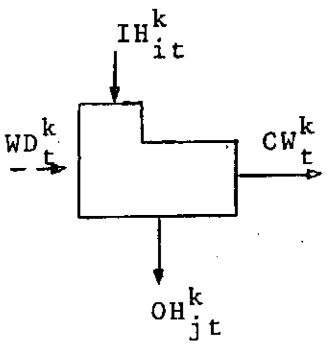
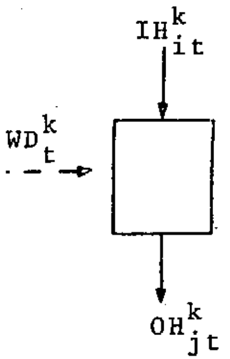
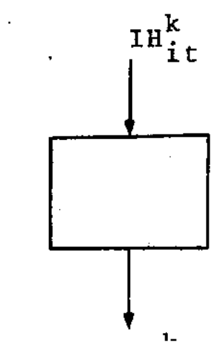
ELEMENTS ESIDENTIAL WATER UPPLY k AT TIME t including public users)	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH_{it}^{k} - amount of water to be delivered to the k^{th} residential area WD_{t}^{k} - water demand (obtained as an output of DEMAND MODEL which is not discussed here)	OH_{jt}^{k}: output water (usually waste water) CW_{t}^{k} - consumed water	–	$\sum_i IH_{it}^{k} = \sum_j OH_{jt}^{k} + CW_{t}^{k}$ $\sum IH_{i}^{t} = a_{t}^{k}, WD_{t}^{k}$ $0 \leq a_{t}^{k} \leq 1$	DESCRIPTION
Economical activities concerned with building a residential supply network	IE_{it}^{k}: construction material energy land use manpower network type	OE_{t}^{k}: cost of the residential supply network		$OE_{t}^{k} = f(IE_{it}^{k}, \text{all } i)$	DESCRIPTION
	IN_{it}^{k}: - OH_{jt}^{k} - water used for: street cleaning, irrigation of public parks	ON_{jt}^{k} - output water quality - aesthetic and health considerations		$ON_{jt}^{k} = f(IN_{it}^{k}, \text{all } i)$	DESCRIPTION

TABLE 1M

ELEMENTS INDUSTRIAL WATER SUPPLY k AT TIME t	INPUT VARIABLES	OUTPUT VARIABLES	STATE VARIABLES	POSSIBLE MODEL (OR MODEL TO BE DEVELOPED)	
	IH^k_{it}: - amount of water to be delivered to the k^{th} user; the water may be obtained by different sources WD^k_t - water demand (obtained as an output of a DEMAND MODEL which is not discussed here)	OH^k_{jt}: - output from the user (usually waste water) - evaporation and other losses - water consumed		$\sum_j OH^k_{jt} = \sum_i IH^k_{it}$ $\sum_i IH^k_{it} = a^k_t \, WD^k_t$ $0 \leq a^k_t \leq 1$	DESCRIPTION
Economic activities concerned with building a particular type of industrial supply system as well as the benefit obtained from the production output	IE^k_{it}: construction materials energy manpower network type	OE^k_{jt}: -cost of the supply network -profit obtained by having the k^{th} industrial plant		$OE^k_{jt} = f(IE^k_{it})$	DESCRIPTION
	IN^k_{it}: OH^k_{jt}	ON^k_t: output water quality		$ON^k_t = f(OH^k_{jt})$	DESCRIPTION

References

[1] Bunge, M., Things, *International Journal of General Systems*, 1, (1974), 183-188.

[2] Kaplan, M. and St. Schwartz (editors), *Human Judgment and Decision Processes*, Academic Press, Inc., 1975.

[3] Meta Systems, Inc. (authors), *Systems Analysis in Water Resource Planning*, Water Information Center, Inc., Port Washing, New York, 1975.