IIASA-PC-1

International Institute
for
Applied Systems Analysis

PROCEEDINGS
OF
IIASA PLANNING CONFERENCE
ON
WATER RESOURCES

June 12-14, 1973

Schloss Laxenburg
2361 Laxenburg
Austria

The views expressed are those of the contributors and not necessarily those of the Institute.

The Institute assumes full responsibility for minor editorial changes made in grammar, syntax, or wording, and trusts that these modifications have not abused the sense of the writers' ideas.

TABLE OF CONTENTS

I. LIST OF PARTICIPANTS

List of Participants

Prof. A. Letov, Chairman

Mr. John S. Alabaster
Head of Pollution Division
Water Pollution Research
Laboratory, Stevenage, Herts.
United Kingdom

Dr. Marcello Benedini
Head, Hydraulic Division
The Water Research Institute
Via Reno 1
00198 Rome, Italy

Mr. Tenière Buchot
Agence Financière du
Bassin Seine Normandie
10/10 rue Capitaine Menard
75015 Paris, France

Dr. Donald J. Clough
University of Waterloo
Toronto, Canada

Dr. Emsellem
Director of the Centre
d'Informatique Géologique
Fontainebleau, France

Prof. Myron B. Fiering
Harvard University
Div. of Engineering and
Applied Physics
Cambridge, Mass. 02138,U.S.A.

Prof. Yoshiaki Iwasa
Dept. of Civil Engineering
Kyoto University
Sakyo-Ku,
Kyoto 606, Japan

Mr. Janusz Kindler
Warsaw Polytechnical Institute
Warsaw, Poland

Dr. Allen Kneese
Resources for the Future
1755 Massachusetts Ave. N.W.
Washington, D.C. 20008
U.S.A.

Dr. Lauterbach
Institut fuer Wassermengenwirtschaft
Schnellerstr. 140
119 Berlin-Niederschoenenweide
DDR

Prof. Wolfgang Loeffler
Prof. an der Universitaet Wien
Wien, Austria

Prof. Ugu Maione
Italy

Eng. Carlo Marchetti
Rome, Italy

Dr. Akira Nomoto
Faculty of Engineering
Osaka, Japan

Prof. Ferenc Rabar
Director of the Hungarian Committee
for Applied Systems Analysis
INFELOR-Applied Systems Analysis
Engineering Institute
Tarogato ut 110
Budapest II, Hungary

Sir Norman Rowntree
Director of Water Resources Board
Reading Bridge House
Reading, Berks., United Kingdom

Dr. Werner Swoboda
Forschungsinstitut fuer den
Donauraum und
Institut fuer Stadtforschung
Waehringerstr. 6-8
1090 Wien, Austria

Eng. Blagoi Uzunov
The National Centre for
Cybernetics and Computer
Techniques
Slavjanska 8
Sofia, Bulgaria

Dr. P.C. Young
Dept. of Engineering
Cambridge, United Kingdom

IIASA

Prof. Howard Raiffa
Director

Prof. Alexander Letov
Deputy Director

Dr. Andrei Bykov

Dr. Rudolf Avenhaus

Mr. Julyan Watts

Dr. Mark Thompson

Mr. John Page

UNIDO (VIENNA)

Dr. Perelet

II. PROGRAM OF THE SYMPOSIUM

June 12, 1973

09:00	Opening Prof. A. LETOV
09:10	Welcome to the delegates by Prof. H. RAIFFA
10:00	Excursion to Schloss Laxenburg
12:30	Lunch
14:00	The IIASA research plans - what IIASA expects from this meeting - Prof. H. RAIFFA
14:30	Report by Prof. A. LETOV on the IIASA research project "Complex Use of Water Resources"
15:15	Answers to questions
15:30	Coffee Break
15:45	General Discussion
18:00	Cocktail-Party at Hotel Herzoghof

June 13, 1973

09:00 - 12:30 &
14:00 - 18:00

Discussion of the research program and its scientific and organizational aspects.
Desirable points for discussion are:

(1) Design of a mathematical model of the LSS for complex use of water resources;

(2) Definition of objectives and alternative ways of achieving them;
composition of the program for modelling and computer application;

(3) Research team structure - staffing the project;

(4) Budget and timing of the research work;

	(5) Proposals by the NMO's of particular rivers as examples for application of general methodology.
12:30	Lunch
Morning & Afternoon	Coffee Breaks
19:00	Dinner at a "Heurigen"(wine tavern)

June 14, 1973

09:00	Continuation of the discussion
11:45	Concluding remarks by Prof. H. RAIFFA
12:00	Concluding remarks by Prof. A. LETOV
12:30	Lunch
14:00 - 18:00	Time for the preparation of comments by the delegates.

III. WELCOME BY THE SYMPOSIUM CHAIRMAN

A. LETOV

"Good morning Ladies and Gentlemen. My name is Alexander Letov and I am Chairman of this symposium.

"It will shortly be my privilege and pleasure to introduce to you Dr. Howard Raiffa - a distinguished professor of Harvard University and the Director of IIASA. Professor Raiffa will have a chance to welcome you on behalf of the IIASA staff, who contributed much to the symposium preparations.

"But now, I would like to take this opportunity to express my pleasure in welcoming you to Baden to participate in this conference. Our main task here is to discuss scientific and practical aspects of the IIASA research project on "Complex Use of Water Resources". We will also discuss the research proposal which was prepared by a group of Soviet experts and distributed to the Member Countries prior to this conference.

"We shall start our discussions now, although delegates of some Member Countries have not yet arrived. We shall discuss the proposed program of the symposium after remarks by Professor Raiffa. Professor Raiffa, please."

IV. WELCOME BY THE DIRECTOR OF IIASA

H. RAIFFA

(Note: Professor Raiffa spoke from outlined notes rather than from a prepared speech. The following outline is a modification of those notes)

I. Introduction and Purpose of the Meeting

A. On behalf of the Institute the Director welcomes the participants.

B. This is the first in a series of conferences of experts.

C. The purposes of the conferences are:

1. to create an informal exchange of views of what IIASA should do in the broad area of research on water resources, and

2. to suggest, rather than to make, policy.

D. When a consensus of opinion seems to emerge, the conference leaders will ask the participants for "devil's advocacy" comments to point out possible pitfalls.

E. The rapporteuriel policy for the conference will permit a frank exchange of views.

1. In order not to inhibit the free exchange of ideas, there will be no tape recording of any sessions nor will there be verbatim transcription of comments.

2. The official minutes of the meetings shall normally show the sense of remarks made without attribution to the speaker.

3. The remarks of the Chairman and the Co-Chairman of conference sessions and, in exceptional cases, the remarks of other participants shall be attributed.

4. No attributions shall be made without prior approval from the speaker.

F. Any participant who has further comments to make should feel free to communicate them in writing after the conference.

G. The participants will receive copies of the official minutes so that they may ascertain whether the minutes have accurately caught the spirit of the conference.

H. The project on Water Resources must not be considered in isolation, but must interact with other Institute projects on Energy and Municipal and Regional Development Systems and on Biological, Ecological and Organizational Systems.

II. Brief History of IIASA

A. The idea for the Institute dates to 1967 and thoughts proposed by McGeorge Bundy in President Johnson's administration.

B. There was a series of negotiations from 1968-1970 among representatives of the Federal Republic of Germany, France, the German Democratic Republic, Italy, Poland, the Soviet Union, the United Kingdom, and the United States.

C. A Charter was drafted outlining the Institute goals in studying problems common to advanced industrial societies.

D. The Institute research would use techniques of cybernetics, decision and control theory, operations research, management science, and applied systems analysis.

E. Bulgaria, Canada, Czechoslovakia and Japan were invited to join the Institute.

F. Two locations, in Fontainbleau and in Laxenburg, were proposed for the Institute headquarters; after a vote, Laxenburg was selected. The Austrian government has continually been helpful.

G. In October 1972 the Charter was signed in London, creating IIASA as an international, non-governmental Institute.

H. The time-table of development has three main overlapping phases.

1. October, 1972 - June, 1973: Organization of the Institute administration.

2. July - October, 1973: Research planning conferences.

3. September, 1973 onwards: Expansion of the Research program. Projected growth:

   a. 30 scientists by September, 1973

   b. 60 scientists by September, 1974

   c. 90 scientists by September, 1975.

I. The scientists are chosen with consideration of geographical distribution, are invited for short term visits or residency up to three years, and are paid salaries comparable to UN professional salary scales.

J. The Institute has two branches: the Council, which is responsible for broad policy, and the Directorate, which implements, directs, and administers the research.

K. The Institute will provide modern scientific support in computer, library, and documentation services.

III. The Institute Research Program: Chosen by the Council and implemented by the Directorate.

A. Planning for the research program has gone through various stages of refinement.

1. Early discussion of the research to be done at the Institute dates back to a meeting in 1968 in Sussex, England.

2. Subsequent discussions took place up to June, 1972.

3. Just prior to October, 1972, the signing ceremony, the Director wrote a paper outlining his reflections on proposed research areas.

4. Council debate produced further comments and changes.

5. In early 1973, the Director wrote a second paper to take into account ideas of the Council Members; this paper stimulated

additional ideas for comment and debate by the Institute Executive Committee.

6. It was decided to hold a series of planning conferences which would create more discussion and help give shape to the research program.

7. In the interim, the Director has a partial mandate to invite scholars to begin research in 1973.

B. As no consensus was possible on a single set of research projects, the Institute will have a "menu" of alternatives within a broad framework of topics.

C. To overcome problems presented by the breadth of the research program, the Institute chose two approaches.

1. The scientists would work on topics with obvious interrelations (e.g. water resources, energy, organizations, control of large scale systems, regional development).

2. The Institute would exploit the infrastructures of existing organizations (the National Member Organizations, UN groups, and other national and international organizations doing concrete work).

D. The Institute would not be a project oriented consulting group and would not act solely as a data collecting institution.

E. Research will be balanced between methodological and applied studies, each aspect serving the other to analyze and find solutions for real world problems.

IV. Expectations for this Conference

A. The discussions will help give shape to the research plans. It is expected that the participants will:

1. express their viewpoints,

2. map out alternate designs for approaching the research,

3. isolate theoretical research topics within the

Water Resource area,

4. suggest *modus operandi* for collaborating with other institutions doing work in this area, and

5. suggest ways of choosing a concrete problem for analysis, if this course appears to be useful.

B. It is hoped the conference will produce preliminary suggestions for a basic library and guidelines for necessary computer support.

C. The participants will also discuss the desirability of doing critiques of current on-going projects and of making retrospective critiques of past projects.

D. There should also be discussion about the types of people the Institute should have to give support to the Water Resources Project (e.g. biologists, biochemists, economists, hydrologists, geographers, meteorologists, geologists, engineers, lawyers, agronomists, regional and urban planners, organizational experts).

E. A final area for conference interest would be identification of natural contact points between the Water Resource Project and other projects (for example, questions of nuclear plants and thermal effects on water systems would involve the energy, water, and ecological projects).

V. PRESENTATION BY THE CHAIRMAN OF THE IIASA RESEARCH PROJECT:

"COMPLEX USE OF WATER RESOURCES"

A. LETOV

"Complex Use of Water Resources"

(Prepared by A.M. Letov, N.N. Moiseev, P.P. Koryavov, and I.P. Belyaev)

There is no need, I suppose, to explain to this group why it is important to use a systems analysis (SA) approach for solving the "Complex Use of Water Resources" problem. This is a control problem of a large scale system (LSS), and we are gathered here to discuss ways of organizing IIASA research on this project. A group of Soviet experts--Professor N. Moiseev, Dr. P. Koryavov, Dr. I. Belyaev, and myself--prepared for this discussion, and distributed to the IIASA NMO's, a paper under the same title. We beg your pardon for our primitive English.

In this paper we did our best to explain that the scientific content of the problem has two parts:

1. the general methodology of SA descriptions, with major emphasis on problems in the complex use of water resources; and

2. an application of this methodology to a particular example (or examples) of a continental river (CR). The example must demonstrate--both in computation and in generation of beneficial results--the effectiveness of SA. If the CR is a real (not hypothetical) river system, we plan to provide clear recommedations for project implementation.

I want you, Ladies and Gentlemen, to consider the paper as a memorandum which attempts to order our discussion, rather than as a final scientific document. You are, of course, free to make any suggestions and to criticize the paper as you may find desirable.

Let me now direct your attention to the first part of the paper. One possible and promising approach is to design a mathematical model of the LSS.

The general methodology of SA begins, in this case, with the process of identification of an LSS as an object of control. This process establishes the correspondence between the systems analysis problem of identification and the problem we usually do in classical control theory. Our difficulty is that there does not exist any kind of input/output ratio analysis procedure--like those widely used in classical control theory--which could be used in our case. In my seminars in the Soviet Union, we have already discussed the problem of LSS identification. We came to the conclusion that only in this particular case could the identification be made, because of our knowledge about the CR itself, about the users of the water, and about various branches of science, including:

- control theory
- mathematics, particularly statistics, probability theory, and stochastic processes
- hydrology and hydrodynamics
- urban development science
- energy, industry and agriculture production
- ecology
- icthyology
- economics
- sociology.

In order to explain how the LSS identification could be done in this particular case, let me start by describing the results obtained at the Institute of Control Problems, at the USSR Academy of Sciences, and at the G.M. Krgyganovsky Energy Institute of Moscow.

Let y_α be a quantity of water which must be used by α users, w_β a quantity of water coming from β inflow, M_1 a set of inflows, and M_2 a set of users which are located upstream from user i. Then we shall have a system of constraints

$$\sum_{\alpha \varepsilon M_1} w_\alpha - \sum_{\beta \varepsilon M_2} k_\beta y_\beta \geq y_i \qquad (4.1)$$

and

$$a_i \leq y_i \leq b_i \quad , \qquad (i = \overline{1,N}) \quad .$$

I will call (4.1) the basic constraints. Here, k_β, $0 \leq k_\beta \leq 1$ is an empirically determined coefficient which reflects the volume of water returned to the CR by users β, a_i, b_i, and N are given positive numbers. If w_α could be predicted for each $\alpha \epsilon M_1$, and if $\phi_\beta(y_\beta)$ is a function which properly reflects the economic interests of user β, we could form the convex programming problem represented by constraints (4.1) and by the benefit function

$$z = \sum_{j=1}^{N} \phi_j(y_j) \quad . \tag{4.2}$$

The solution of (4.1) (4.2) is described in [1].

The model (4.1) could be extended successfully to include aspects of water use technology. Let me demonstrate how it could be done with agriculture as an example. If y_1 is a volume of water used for agricultural purposes, the equation

$$\sum_{\alpha=1}^{n} \sum_{\beta=1}^{m} w_{\alpha\beta} = y_1$$

links constraints (4.1) and the constraints written in our paper (Appendix A). By the same techniques of operations research, one can build other links between the basic constraints and constraints reflecting energy, industrial production, or water use for transportation or for municipal supply.

There are two ways to describe a harmful effect of water pollution. In the first we can design a new algebraic constraint, provided we can regard the chemical components of artificial fertilizers as the state variable of the LSS. Another possible approach considers the CR as a part of agriculture. Both ways are described in the paper, "Complex Use of Water Resources".

The social and economic sides of the project include consideration of: population growth, employment parameters, wage benefits, the upper limits of different cost matrices, and criteria for the project's potential benefit. The maximization of these criteria will provide a feedback control principal for applying the results to the LSS. Thus the gap which sometimes occurs between plans for the LSS and actual operation will be decreased. The selection of these criteria--which might be either scalar or vector-valued--is a special question for this project.

I might mention that a problem of optimizing a vector-valued criterion was described by the Russian writer N. Gogol in his play, "Marriage", written at the beginning of the eighteenth century. A lady who was going to be married faced the problem of selecting her husband from a group of four candidates. The lady's first choice was to have a husband who synthesized the best features of each of the candidates: the mouth of the first candidate, the nose of the second, the solidity and reliability of the third, and, last but not least, the moustache and bravery of the fourth. That, clearly, was impossible. Thus the unfortunate lady ended up with nothing because she was unable to formulate the problem of vector-valued optimization. Our situation, fortunately, looks much better, as the recent literature includes many publications dealing with the problem of vector-valued optimization.

All of the features I am speaking about reproduce the structure of the mathematical model which, in this case, must reflect in its design both common sense and experience. The problem of identification mentioned above relates to definition of the structural parameters and some functional dependences for particular examples.

After defining the Supremal Goal of the LSS operation and defining alternative methods for its accomplishment, we shall be able to examine a control aspect of the project. This examination should include:

- ordering of all subsystems of the LSS
- establishment of their compatibility
- designing of the LSS multilevel hierarchy
- determination of information need and availability
- coordination of control operations between supremal and infimal decision units

- clarification of the sensitivity of the LSS to different circumstances, particularly to uncertain events.

In our attempts to discover the behavioural characteristics of the LSS under the last point above, we should use not only classical probability and decision theories in the presence of uncertainty. In cases not amenable to description using mathematical symbols, we should try to use new concepts, such as the concept of "Fuzzy Sets", developed by Prof. L. Zadeh.

The examination can be implemented on a digital computer (DC). The main goals of the modelling include:

discovery of the LSS admissible trajectories, their behaviour, and the influence of admissible control policies;

quantification of effects of all types of disturbances;

discovery of the best policy for maintenance of the LSS; and

risk estimation for operating the LSS in the presence of uncertainty.

Development of the research program , expected results and their presentation, composition of the IIASA research group, and the program budget are all described in our paper. I have nothing to add here. Speaking on behalf of the authors, I must say that we will be especially thankful to the participants here for clarification of the last four points of our program.

[1] S. B. ELAHOVSKY, B. L. ROITBURT, S.I. SOROKINA, V. I. BUJAKAS, "Methods of Solution to the Operational Problem of the Distribution of Water Resources and their Comparative Evaluation", The International Symposium on Water Resources Systems, Praque, 1972.

VI. SUMMARY OF QUESTIONS BY PARTICIPANTS UPON THE RESEARCH PROJECT

Immediately after Prof. Letov presented the "Complex Use of Water Resources" research program, several of the conference participants responded with questions for him.

The first question concerned use of the vector-valued optimization technique for the problem, "Complex Use of Water Resources." Although Prof. Letov's personal experience has been primarily with the problem of scalar-valued optimization, he felt that the vector-valued optimization methodology was applicable to the problem of water distribution and had been foreseen in the program.

Prof. Letov was asked about possible methods of taking water quality into consideration. He replied that water quality would be taken into consideration in different ways. But any of them lead to the introduction of phase-space constraints, the nature of which depends upon the way "water quality" is interpreted. Particularly in the case of agriculture and application of artificial fertilizers, water quality should provide some necessary biological life in the continental river. This leads to the introduction of the constraints mentioned in the paper, "Complex Use of Water Resources."

The next comment pointed out that the models of such kinds of constraint already exist in the literature and could be incorporated into the research program model. Prof. Letov agreed.

The next participant commented on the staffing of the IIASA research group, which consists mainly of applied mathematicians rather than water scientists. Prof. Letov agreed to accept the incorporation of water scientists, but their number would depend upon the IIASA budget. Considerable assistance in staffing could be obtained from the other IIASA research groups and from institutions in the member countries.

The next participant commented that the proposed model was very interesting but not perfect. It is extremely difficult to generate utility functions and bring them into a model as this one requires. He suggested that the project leader consider a new approach if the proposed model is used:

a) There should be simulation of the physical and technical properties of the river.

b) Different consumption levels should be assumed and their effects studied.

c) An attempt should be made to find appropriate trade offs between the user groups.

This participant further felt that the suggested budget was much too small for studying a complex system such as the Danube.

Prof. Letov replied that the three points mentioned above could be incorporated into the model if we know the facts about physical and technical properties, consumption level, and demands of user groups. He agreed that the budget was too small, but if the Danube were chosen as the application example, the interested NMO's would take part in the study.

VII. FORMAL WRITTEN COMMENTS UPON THE RESEARCH PROJECT: "COMPLEX USE OF WATER RESOURCES"

Assessment of the IIASA Research Project on Complex Use of Water Resources

Eng. Blagoi Uzunov
Bulgarian National Center for Cybernetics
and Computing

We acquainted ourselves with great interest with the program entitled "Complex Use of Water Resources", worked out by A.M. Letov, N.N. Moiseev, P.P. Koriavov, and I.P. Belyaev. The program begins with an explanatory note on the problem: "The main goal of the project's research is the development of systems analysis methods to allow one to take into consideration all [factors which influence the problem of the complex use of water resources] and to give to decision makers recommendations which maximize profit under conditions of ecological equilibrium."

The program goes on to say that the research should include at least one practical example for application of the model. This should be modelled on a digital computer, both to demonstrate the effectiveness of systems analysis concepts and to generate practical recommendations for implementing the model. Part 2 of the program treats hydrological, hydrodynamic, and geographic aspects of the model.

The most important part of the model is its economic aspect. The program notes with justice that this is the most important and most difficult part. Here are proposed some mathematical relations among productive land and pastures and the amount of water needed for production purposes. This is a simplified version of the region's economy. It assumes that the water has not been polluted. Also treated are the impact of industrial, agricultural, and town development upon the environment and the ecological balance.

After treatment of questions linked to the improvement of the model, to the defining of tasks and alternatives, and to the goals of modelling, a time scale for the program is presented. It is proposed that the program be carried out by a ten member team of specialists working over a period of five years. It will cost about 1,300,000 US dollars.

We take the liberty of making the following notes on the program:

1. The problem of the "Complex Use of Water Resources" in a given country, region or catchment area of a big or international river--e.g. the Danube, the Tisa, the Nile--is linked with the solution of three main problems:

a) Flood, high water, and ice control

b) River water pollution control

c) Water resource distribution control.

(The distribution control should be operated to meet optimally the needs of the various water users and thus requires an accurate and precise description of the water economy.)

Solving task a) requires development of a program for short-range and long-range forecasting of flood flows as a function of rainfalls, snow thaws, and the run-off coefficients.

Solving task b) requires forecasting the increase of water pollutants (from industry, from agriculture, and from population centers), the construction of water treatment plants, and the existence of other efforts to protect water resources against pollution, and then combining these forecasts.

Solving task c) requires creation of a procedure for preparing a water economy balance acceptable to all countries crossed by the river, preparation of the balance itself (taking into account river pollution), analysis of results, and development of a model for the distribution of the water resources.

The above tasks cannot be solved by the traditional classical methods of study simply because the end results are influenced by many factors whose interrelations cannot be established by currently existing methods. The examples we have (the mathematical model by D. Zanobetti and H. Lorshere of the Mekong river delta and others) indicate that only the methods of systems analysis--which permit consideration of all influencing factors--will help us devise means for prevention of damage from floods, high waters, and ice, the abatement of pollution, the writing of a water economy balance, and the development of a system for controlling water resource distribution.

2. As already mentioned, part 2 of the program treats the hydrological, hydrodynamic, and geographical aspects of

the problem. Without underestimating the above aspects, we should note that the science of water resource utilization contains an economic aspect as well. This aspect includes, among others, analysis of data from the hydrological studies, of data about water consumption, and of the costs of various solutions. This last remark is necessary in order to stress the need to include in the team a specialist on water economy studies.

3. By a decision of the government of the People's Republic of Bulgaria, we have been developing for three years a naticnal system for the complex utilization, management, and pollution control of our water resources, applying the methods of systems analysis. The structural and functional model of the system has already been worked out. We are now working on a design to apply it to a limited area of this country's territory (parts of the Iskar river valley near Sofia). In order to acquaint the participants in the Symposium with the essence of our work, we enclose "A Concept-Model for Setting-Up of a National System for the Complex Utilization, Management and Pollution Control of the Water Resources in the People's Republic of Bulgaria" (Appendix B).

Comments on Complex Use of Water Resources

Peculiarities of the Italian Situation

Localization of water resources and their exploitation have different characteristics in Italy, according to the degree of economic and social development in the various areas. Two distinct cases can be specified:

1. Resources located in basins of large rivers (Po, Adige, Tevere, Arno), where all the possible reservoirs have been built for electric power. Further exploitation will mainly be for the development of agriculture and industrial activities, inland navigation, and water quality preservation.

2. Resources located in small basins (especially in the "Mezzogiorno" and in the Isles) where it is possible, and necessary, to build reservoirs for run-off control and for agricultural and industrial uses of water. Here, water quality preservation is also of prime importance.

As is evident, the two cases differ: in the former, water resources management fundamentally consists of managing the conflicts among present exploitations, with no consideration of further development; in the latter, planning and design are of greater interest. In addition to the problem of water quality preservation--common to both situations although they differ greatly--there is also the problem of flood control and of soil erosion prevention. However, such problems must be solved differently for the two cases: by introducing a further series of constraints in the case where large reservoirs already exist, and by assuming appropriate sizes for future works in the other case.

The above mentioned peculiarities create a problem in Italy completely different from that in all other large basins, where, as is well-known, systems analysis (SA) is continuously applied.

Management studies should be concentrated on the following topics:

- surface and underground water hydrology

- cost-benefit evaluations of work constructions and operations
- interaction of development activities connected with water exploitation
- impact of water use on social, political, and daily life
- water quality and its influence on the various uses
- criteria for introducing treatment plants to permit re-use of initially undesirable water.

In Italy, these topics, seen from the perspective of SA, must be studied under the criteria summarized below.

Hydrology

Even though, for most of the basins, there exist quite reliable series of historical data on both flow and meteorological conditions, there are difficulties nevertheless. There is a lack of processing techniques to assess flows in typical sections (which generally differ from those reported in the measures), to establish the correlation between inflows and outflows, and to identify flood generation in various situations. This implies the need to adopt up-to-date data collection and filing techniques and to construct complex models utilizing advanced mathematical-statistical techniques. The choice of a suitable time scale is also of special interest, since it must be adapted to the particular phenomenon to be studied and to the modalities of the water used to be considered. It might become necessary to adopt very short time scales (week, day). These scales are closer both to representation of natural phenomena and to specification of some modalities of use, especially those characterized by large "peaks."

For underground water, besides the need for collection of reliable data on the geological and hydrogeological nature of the soils, it would be useful to improve the methodology for writing the hydrogeological balance. One hopes for a better understanding of the aquifer's behaviour, of natural and artificial re-charge phenomena, and of the possibilities for exploitation.

Cost and benefit components

For works to be undertaken, there are reliable criteria for prior evaluation of costs, but these criteria often do not take sufficient account of possible variations which may arise during actual construction. For example, the use of advanced technologies or the occurrence of certain events may have repercussions on unit prices and cost. It is still very difficult to assess operating costs and their dependence on physical variables and management rules. The existing methodologies for benefit evaluation are still more complex because of the occurrence of intangible factors. In most cases, the work has not only immediate effects but also a series of economic, political, and social consequences. It is difficult to establish the character of the total result.

Interaction of development activities connected with water exploitation

Even though such a topic relates to management models, it seems necessary to establish a series of assessments based on real data. For some uses, these interactions are not yet well known, e.g. in the case of recreational activities, whose meaning is not yet defined. Also, for the so-called "ecological" uses, exhaustive information, suitable for focusing the essential features of such uses, does not yet exist.

Impact of water use on social, political, and daily activities

There are various criteria and models for examining aspects of water quality. These include specified standards for bodies of water and for discharges, and the definition and reproduction of phenomena related to polluting agents in the water. A lack of up-to-date measures, which would allow efficient application of the models under study, is still universally felt.

Criteria for introducing treatment plants to enable use of initially undesirable water

This is one of the most important aspects, since so-called "unconventional sources" must more and more be integrated with available natural water resources. The need for meeting increasing demands and the shortage of available water require consideration of reusing discharged water after suitable treatment, or of exploiting sea or brackish water after appropriate desalinization. In essence, the problem consists of finding technological measures for implementing the processes most efficiently from the technical and economic points of view. The aspects of major interest are the assessment of the feasibility of the treatment plant to be introduced among the "conventional" sources of water supply and the analysis of its competitiveness. This type of problem is particularly salient in certain regions of Italy, especially in the south and in the islands.

Present Activities in Italy

In Italy, few institutions are interested in this type of study. With the exception of some limited cases where SA is used for specific professional purposes, we can list the following bodies:

- Water Research Institute of C.N.R. (National Research Council)

- The "Cassa per il Mezzogiorno" - Systems Analysis Committee

- The E.N.E.L. (Electric Power National Organization)

- The Hydraulic Engineering Departments of the Universities of Bologna, Cagliari, Catania, Padova, Pavia

- The Automatic Engineering Group of the Department of Electronics and Electrotechnics in the "Politecnico" of Milan.

SA is used in the universities for limited purposes on sub-topics of research and for teaching and academic training. In the first three institutes mentioned above, important programs are being carried out. They have different aims, according to the mandate of the institutes. These programs are described below.

The Water Research Institute

This institute, which belongs to the National Research Council, has among its purposes that of carrying out research activities in the fields of hydrology and hydrogeology, especially in methodological aspects of planning the exploitation of water resources. In particular the Institute has specified new techniques of survey research and data processing. In these fields, the Water Research Institute has long undertaken two programs where SA is used:

a) Study for the planning and the management of water resources in a large river basin--"The Tiber Research". The complex analysis is applied, as an example, to the Tiber basin and carried out with the cooperation of many national and foreign experts. The main guidelines of this project (in which more than 200,000,000 lire have been invested) are listed in Appendix C - Part 1.

b) <u>Study on the problems of underground water management</u>. This research, the guidelines for which are not yet fully specified, aims to give a full representation of the behaviour of the underground waters--the phenomena of seepage, artificial and natural recharge, and their exploitation. Other phenomena are also taken into account, such as salt water intrusion into coastal aquifers and the seepage of polluting discharges. Among various types of subsoil, the Institute has stressed the importance of fractured rocks, mainly in the calcareous zones. These are quite common in some Italian regions.

<u>The "Cassa per il Mezzogiorno" - Systems Analysis Committee</u>

The "Cassa per il Mezzogiorno", founded to meet the economic development needs of the southern and insular regions, has an excellent staff able to design, finance, and supervise works of public interest.

Recently, an ad hoc Systems Analysis Committee has been set up to introduce new methodologies for problems of planning and managing resources in the areas under its concern. The water resource system in Basilicata was taken as an example for determining choices for intervention and their feasibility for permitting multipurpose use of the water resources. The plan should determine:

a) size and date of initial operation of the various possible reservoirs. If size is set equal to zero, the reservoir is not necessary;

b) sizes of water mains and dates for putting them into operation;

c) size of water districts and dates for beginning irrigation. Here too, size set equal to zero means that the district has been disregarded;

d) water amount with its temporal distribution, and water amount delivered to each water district;

e) water amount delivered to industry;

f) water amount delivered for potable uses;

g) management criteria concerning reservoirs for the period taken into account;

h) capital cost of the project;

i) size of possible power plants connected with the inputs;

j) size and power of any necessary desalinization plant.

Due to the number of unknowns, the problem presents very complex alternatives. A specific alternative is characterized by the number and technical characteristics (e.g. height) of the reservoirs, the size of the mains, the amount of water to be delivered to each use, and so forth. Out of the great complexity of the problem, the following aspects can be specified:

a) hydrologic systems,

b) various alternative costs,

c) benefits connected with the various alternatives, and

d) demand for potable uses.

The E.N.E.L. (Electric Power National Organization)

Within the scope of planning for power production, the E.N.E.L. has applied SA to many situations, as described in Appendix C - Part 2.

The Italian Universities

Appendix C - Part 3, a description of the model prepared for the Arno River problem, gives an example of a project carried out in an Italian university. This model was built at the University of Pavia Hydraulic Institute, in connection with the IBM Center of Pisa.

Comments and Notes on the IIASA Research Project for Complex Use of Water Resources

Y. Iwasa, Japan

This is not a general statement of the views of Japanese specialists and engineers concerning the proposed research program, "Complex Use of Water Resources but only my own personal comments on this matter.

Objectives of Complex Use of Water Resources

In the systems analysis approach to complex use of water resources, the supreme political objectives can easily be formulated in qualitative terms from the perspective of water management. The goal is to find an optimal point in the four-dimensional objective space of national benefits, regional development, environmental preservation and enhancement, and international coordination. The analysis will be applied to both large and small scale river systems.

The abstract procedure defined here yields two other problems on a lower level. The first problem is that the goal is always shifting over time with changes in the socio-economic characteristics of the watershed in question. Therefore, the temporal sequence of engineering work, management, operations, and so on--chosen to achieve the objectives--must be simple and flexible enough to permit response to environmental changes. The second problem is to determine how to realize the political objectives by administrative and technical tools. Our main concern is with this problem. If the water resources are unlimited, realization of the goals will simply require engineering works like channel regulation, reservoir construction, or water transfers. We have, however, only limited water resources throughout the globe. Furthermore, spatial and temporal distributions of water resources are not uniform. A matrix expressing water itself as a natural resource should be transformed into another matrix expressing water resources in terms of the broad needs of man and his environment. Comprehensive management or optimization of water resources to meet all needs must be attempted.

Identification of Watershed

Water resource problems occur within a watershed, where land, water, man, and other biota coexist. Our problem of water resource systems starts from the identification of the watershed. Usually, it can be divided into the following geomorphological, hydrologic, economic, social, biological, and cultural aspects.

The geomorphic aspect is a basic characteristic of the watershed and will be described by linear, areal, and three-dimensional features of the basin. The basic knowledge comes from the sciences of geology, geography, meteorology, and geoscience.

The hydrologic aspect characterizes the basin with respect to its inputs and outputs. All of the hydrologic features are broad, but the main part is the response of the watershed to rainfall as input and runoff as output. These are treated as either deterministic or stochastic, and as either physical or mathematical.

Economic aspects relate to man's activities in agriculture, forestry, fishery, industry, and transportation. When introducing economics into water resource development and management policies, cost-benefit analysis is used. In water resource development, and especially in complex uses of water resources, we are primarily concerned with projections of economic activities in the total watershed system.

The social aspects are the acts and vestiges of acts of coordination by inhabitants of the watershed. They include patterns of land use, community organization, division into private and public properties, effects of local history, definition of public interests, and so on.

Biological (or sometimes, ecological) aspects seem new because of recent enormous activity in production, circulation, and disposal. Flora and fauna are always affected by our use of water resources.

Finally, cultural aspects originate in the richness of our monetary, physical, and mental circumstances. Life style, recreational activities, and tourism are in this category. They are always intangible parameters characterized by complicated features.

Possible Approaches to Description of Water Resource Problems

As we see from the preceding description, all the water problems involving water resource systems are multi-faceted. Rare cases present a single-aspected problem. Our past experiences show that the above aspects can be divided into three categories: technical or engineering, economic, and environmental. Geomorphological and hydrologic characteristics of the basin are studied in the technical approaches. This is the oldest, but still the main, branch of water resource development, because it provides the basic engineering knowledge. A rather recent fashion is to consider economic systems, as typified by cost-benefit studies. Here the system is expressed in monetary units or the like. Such an approach becomes appropriate with activities large in magnitude and extensive in scope. Corresponding to the tangible benefits, there are intangible benefits to evaluate. Social and perceptive characteristics are substantive examples of aspects concerned with intangible benefits. These aspects will continue to grow with our wealth. Since real expression of such intangible, emotional and aesthetic values is not treated by the economic model, a new model will have to be developed. Environmental approaches are a response to such a need stemming from recent trends in our lives.

Thus, the three sides of engineering, economics, and environment are observed in such water management studies as proposed by "Complex Use of Water Resources." These aspects are not currently combined. At the moment, only some compatibility studies among the three approaches to the comprehensive systems expression of water problems will be made, although our final aim is, of course, to unify them totally.

Desirable Attitude of the Institute

Apart from the scientific expressions of water resources and their associated objectives in systems analysis, we must be aware of the legal and institutional aspects of the water and its environment. In almost all countries, water should be for public use; the problem comes, then, in defining public use. The solution changes from country to country at any given moment and from time to time in each given country. This is simply another description of seeking an optimal point in the four-dimensional space of political objectives. A further complication is the legal system of rights attached to water and to water uses. If the water use is approved by the traditional prescriptive right system, possible changes in water use become extremely difficult. Japan exhibits typical examples. Systematic operation and management of water resources, supported by scientific knowledge of systems analysis, is not hoped for. There will be other cases in other member countries.

The Institute, as well as each National Committee, should attempt to understand real situations of water management in the member countries. If this is done, the true long-run objectives of the Institute may be attained, and the fruitful future success of the Institute will be welcomed by many associated agencies and institutions. Note that this course of action depends mainly on manpower. The Institute should be very careful to invite specialists from the member countries. Also, to insure the successful establishment of the Institute, attention should be paid to making close contacts with international academic and professional associations and institutions as many of them are concerned with water resources from many different points of view.

Some Suggestions to the Institute

The following suggestions concerning water resources research projects to be conducted at the Institute will reflect the Japanese view.

1. The Institute should always maintain two, interacting facets in its research projects: methodology and application. Methodological studies will augment the practical state of the art for the future, and applied studies will support the basic knowledge in methodological research. We can contribute much to the promotion of methodological research. However, because of the geographical circumstances, Japanese specialists will not participate in applied studies, such as a particular case study.

2. As in other fields, the construction of the models is of utmost importance. Especially in water resource systems analysis, the methodological procedures for model making are likely to undergo much additional development. Choice of procedures and selection of research groups will determine the future direction of the Institute to some extent. Digital simulations in water resources systems analysis will be made soon. Thus, Institute policy should strongly emphasize such efforts.

3. The permanent involvement of specialists in chemistry, biology , and other fields is necessary. They will be

invited according to Institute conditions. However, a meeting on water management and water resource development should be held before the Institute's research starts. Participants should be water managers of all levels in each member country. However, one should not expect retrospective case studies, which have already failed (in the Water Management Section Group of OECD).

4. We will gladly suggest distinguished experts to visit the Institute to discuss specific areas. The duration of their stays will range from one week to three months, depending upon your desires.

Some Notes on the Research Program for the IIASA Project "Complex Use of Water Resources"

J. Kindler, for the Polish Committee

Introduction

In light of the well known and world wide problems related to the use of water resources and their development, the IIASA initiative to undertake a five year research program on "Complex Use of Water Resources" merits great appreciation. In Poland there are special reasons for great interest in the contemplated research program. First, the mean rate of available water resources per capita in Poland is one of the lowest in Europe. And second, there is a tradition already two decades old of water resources planning on a national scale, including the recently completed "Planning Comprehensive Development of the Vistula River System" project (carried out with the assistance of the United Nations Development Program).

In addition to investigations directly related to water resources planning, long-term special research projects were undertaken about fifteen years ago at the universities, especially at the Warsaw Polytechnic University. These projects concentrated on such topics as stochastic hydrology, application of statistical methods for hydrological and meteorological forecasting, theory of storage, optimization of operational plans for multipurpose reservoirs, generation of synthetic hydrological series, and, finally, water resources systems.

In 1968, a special research group was organized at the Warsaw Polytechnic University for preparation of the methodological foundations for the Vistula System Project in cooperation with "Hydroprojekt" Consulting Engineers, Warsaw, and with Water Resources Engineers, Inc., Walnut Creek, California, U.S.A. (contracted by the UNDP). Professor Zdzislaw Kaczmarek was in charge of the Polish group. The results of the research, although far from complete, have conclusively demonstrated the value of adapting modern tools of operations research and systems analysis for aiding the selection of the best investment alternatives.

In addition to the actual results of the research, the educational aspects of the Vistula System Project are especially worthy of mention. The UN fellowship training program focused on the application of systems analysis to various water resource problems. Out of numerous training programs, (most of them implemented in the USA), particularly important was the three month long course on water resource systems organized by Water Resources Engineers, Inc., for ten members of the group headed by Prof. Z. Kaczmarek.

At present, the core of the Vistula System Project research group is employed at the Institute of Environmental Engineering of the Warsaw Polytechnic University. The Institute is directed by Prof. Z. Kaczmarek, who is also Chairman of the Water Resource Committee of the Polish Academy of Sciences.

The Polish institutions concerned with water resource systems would like very much to participate in the research program on Complex Use of Water Resources. At the Institute of Environmental Engineering, there is considerable potential for actively engaging in research on the development and adaptation of systems analysis to water resource problems. Special research teams consisting of water resource engineers, economists, and mathematicians having considerable experience in systems analysis, could be assigned to parts of the project, within the overall framework of this international effort. Senior Polish research workers might also participate in the central IIASA research team. The Warsaw Polytechnic Institute has its own computer center with an Odra-1204 machine. Also accessible in Warsaw are more powerful computers such as the IBM 360/50, the ICL-1900 series, the Odra-1325, and the Odra-1304.

General Comments on the Research Program

The main project goal is to develop systems analytical methods which will permit us to consider all aspects of the comprehensive use of water resources and which will give decision makers recommendations assuring maximum profit under conditions of ecological equilibrium. Let us concentrate first on some of the most important aspects of the comprehensive use of water resources.

A) Hydrological

Under this item falls everything related to the quantitative availability of natural water resources, with due regard given to their temporal and spatial distribution within the system boundaries. Since precipitation as well as streamflow are essentially stochastic quantities, application of the theory of stochastic processes seems indispensable in this part of the research program. A decision should be made as to which part of the hydrological cycle will be covered by the project. Since operational control of the system is mentioned in the research program, rainfall-runoff modelling as well as hydro-meteorological forecasting probably will have to be incorporated into the project. The problem of synthetic hydrology, and its possible use in systems analysis in a deterministic environment, should also be reviewed. The research program should probably contibute ideas about the conjunctive use of surface and underground water resources.

B) Water use (quantity and quality)

All water use and waste discharge points must be identified. This problem is closely related to overall social and economic development planning, as well as to regional planning. In analyses using projections, due regard must be given to the problems of technological progress and of substitute measures (e.g. reduction of water requirements by production technology changes). The risk element in assessing future water requirements must also be taken into account. The concept of benefit and loss functions could probably be employed in the water use and waste discharge analysis. In any case, most of the problems to be analyzed under this item must be based on sound economic considerations.

C) Social and ecological (environmental)

Here, the problem is to recognize nonquantitative dimensions of the water resources system which must be integrated with the more quantitative aspects discussed under Item B.

D) Engineering and management

This item includes analysis of all potential investment and noninvestment measures allowing those transformations of natural water resources (Item A) which satisfy various requirements (Items B and C).

Without a doubt, in water resource systems we are dealing with an unusually broad spectrum of problems which are best summarized as the identification of adequate criteria for evaluating the system's social and economic performance. An international research group representing countries with different social and economic systems should probably be assigned to this extremely important part of the project.

The division of the program into a general methodological part and a demonstration part is well thought out. In this regard, selection of the proper demonstration basin is of special importance. In our opinion, the basin should, first of all, contain a large number of situations characteristic of different types of water resource systems. moreover, availability of basic hydrologic, water use, economic, and other data will be important factors in the choice of a demonstration basin. To make the methodology also useful for developing countries, it would probably be useful to demonstrate possible ways of solving the problem with an inadequate data base (especially for hydrological data). The international character of the demonstration basin seems less important.

The proposal to consider three basic situations in the project is appropriate. These situations would be the design or planning stage, the operational stage, and the capacity expansion stage. In many current water resource projects not enough attention is paid to the actual operation of the system. Here, control theory might make a significant contibution. In Poland there is a limited number of potential sites for construction of storage reservoirs; therefore, research about day-to-day management of complex water resources systems is of special importance. The problem here is to develop optimum but relatively fixed, operational rules for the system and for each of its elements, anticipating at the same time short-term changes in operation based on forecasts of changing system inputs.

Completion of the project by publication of a handbook on "Complex Use of Water Resources" is an excellent idea.

The final comment is on the composition of the IIASA research group. Since operations research and systems analysis approaches are presently used by numerous organizations actively engaged in the field of water resources, it seems that the IIASA research group should also include specialists on water resource systems. The combination of their experience with the experience of mathematicians specialized in LSS control theory should make the project an outstanding success.

Summary of Discussion and Recommendations of the United States National Academy of Sciences Panel for the Research Program of the International Institute for Applied Systems Analysis

"Complex Use of Water Resources"

1. Case Studies

The Panel felt that it would be questionable for the Institute to move directly into a comprehensive study of a large, complex river basin. Experience of the Panel members suggests that the data collection needs in the technical, engineering and economic areas might be beyond the capabilities of the Institute and such an enterprise seems inappropriate for the sort of staffing and scale of operation now envisaged. Nevertheless, focusing on actual cases is very desirable for lending concreteness to the exercise; to be useful, systems analysis must come to grips with real cases. Two regional case type activities were suggested as possibilities. They could be regarded as preparatory work for a more ambitious case study.

a) An international comparative analysis of the application of systems analysis to regional case studies and planning enterprises could be very valuable. This activity is already contemplated by the Institute.

b) A region for which planning has been done and considerable data have already been collected and at least partially analysed, and where an effort was made to use systems analysis, could be re-studied. In most of these earlier studies, the application of systems analysis has been rudimentary. Experience in the United States has shown that such re-analyses can yield methodological improvements and often shed new light on policy alternatives. Studies of the Delaware and the Potomac rivers in the United States by various research institutions support this conclusion. Suggested possibilities for the Institute are the Vistula in Poland and the Ruhr in Germany. In both instances much information has been collected and some efforts at applying systems analysis undertaken. Also, both studies have international implications, being connected with major international rivers.

2. Methodological Studies

The Panel felt that the Institute is in an excellent position to make some major methodological contributions, for example:

a) Linkages in Models - There has been a tendency to try to build ever larger and more comprehensive models of water resource systems. While in principle this is laudable, in practice it leads to considerable difficulties. For example, some extremely large mathematical programs have been constructed which have taxed computational capacity (it is easy to invent problems beyond the capability of even the largest computers), raised questions about accuracy of results, and obscured sub-problems of interest. One important area of methodological study is how such large problems can be decomposed and the component problems coherently linked, e.g. through the use of shadow prices.

b) Stochastics and Dynamics - Deterministic static models have desirable features from the point of view of achieving solutions, while dynamic and stochastic models more nearly mimic reality. How the strongest features of each of these can best be combined to achieve useful results is an important problem of methodology.

c) Uncertainty - In the face of true uncertainty it is useful to think of other than the usual optimizing approaches. Stability, sensitivity and irreversibility become important points of reference in such situations. Decision making under uncertainty, which characterizes all realistic situations, is an old, well-recognized problem, for which no entirely satisfactory solutions have been put forward.

d) Operation of Systems and Control Theory - There may be important possibilities for applying formal optimal control theory to systems operation as well as to planning problems. The former is a relatively neglected area. For example, in operating flood control reservoirs one may wish to find some optimal function of depth and duration of flood water in scheduling releases.* The possible application of

---

* This suggestion was made after the meeting by Prof. Loucks, who was unable to attend.

optimal control theory of water resource management is a methodological area of significance for the Institute.

e) Evaluating Outcomes - In all societies where systems analysis is applied to water resource management the problem of evaluating outcomes exists. The conceptual basis for evaluating such outcomes is necessarily somewhat different in planned societies than in those using predominantly market systems of resource allocation. In the former, the main consideration may be the achievement of planning goals. In the latter, appeal is made more directly to consumer preferences. But work in the evaluation area would be important in order to identify similarities and differences and to exchange information about concepts, methodologies, and empirical approaches.

3. Studies of Subcomponents of Larger Systems

The Panel felt that important subcomponents of the larger water resources systems are poorly understood and that the Institute might do important work in improving basic understanding and modelling of these systems. Several suggestions were made--without pretense of being exhaustive.

a) Ecological Models - The ecological models presently used in water resource planning are rather rudimentary. This is true even though the response of ecological systems to various changes (rate of water flow, polluting inputs) are often of primary interest. The development of improved dynamic aquatic eco-system models may be regarded as a matter of some urgency. One specific suggestion was that such models should permit analysis of repairing ecological systems after an insult has occurred, e.g. by replanting desirable species from a stock, rather than by trying to prevent the insult, which in some cases could be quite difficult and costly. This approach was called the "environmental zoo."

b) Conjunctive Use and Management of Surface and Ground Waters - While the interrelatedness of surface and ground waters has long been recognized in principle, it has had little influence in practice. Often the linkages in these systems are poorly understood, and the basis for management models is weak or non-existent. This might be an area where international pooling of knowledge and technique could be very useful.

c) Non-point Sources of Pollutants - A grossly neglected area in water quality management is non-point sources of pollution--for example, pollution from agricultural run-off. An examination could be made of ways systems analysis could contribute to understanding of this phenomenon. As an example, an approach similar to that embodied in statistical watershed models used to predict run-off might be tried.

4. Staffing

The Panel expressed concern that staffing might lean too heavily in the direction of mathematicians and statisticians. While these skills are, of course, at the heart of systems analysis, by themselves they can achieve little depth in the substance of the problems of concern. They should be strongly complemented by engineers, chemists, biologists, and social scientists (especially economists). The latter should be selected in part for their interest in, or experience in, systems analysis approaches.

5. Inquiry Concerning Appropriate Methodology

The Panel commented that not all major problems are necessarily best addressed by the applications of systems analysis. It was suggested that a few major water uses be examined to learn what types of analytical approaches might best be used to increase the effectiveness and efficiency with which they are managed, and to learn where formal systems analysis fits into this pattern. Areas mentioned were urban waters use and irrigation.

6. Developing Countries

When irrigation water use is considered, it is soon apparent that this largest single consumptive use of water is heavily concentrated in developing countries. While it is understood that the main thrust of Institute activity is to be in the direction of common problems of developed countries, the Panel felt that it would be useful to bring in a few visiting scholars from developing countries. In this way a useful educational function could be performed and a broader perspective attained concerning global water problems.

7. The Institute and Data

The Panel felt that it would not be desirable for the Institute to try to establish and maintain an international data bank. At the same time, the Panel felt that the Institute could fulfill an important role as a clearing house and could help standardize data collection to the extent desirable. In this connection, more or less formal modelling of water resource systems could offer particularly helpful guidance, since in principle the construction of models should precede data collection. For example, one member of the Panel had the experience of taking a standard environmental model used in one country to another country. He then found that it could not be operated because the particular type of data it needed had not been collected in specifically the form required. The Institute could play a role in indicating the types of data needed for systems analyses of various types.

VIII. POST-SYMPOSIUM REFLECTIONS OF PARTICIPANTS

How Does the Institute Help Me?

M. Benedini

1. The Institute's role should be that of fostering the most advanced studies in those fields and at those levels that are not easily achieved in the national institutions.

2. To achieve this goal, the Institute should choose, among the existing studies carried out in the several member countries, those kinds of problems having more general interest for all the participants.

3. Analysis of large systems is not necessarily the best tool to achieve the goal. Small systems or sub-systems seem more suitable.

4. The organization of the work should comply with the following needs:

   a. flexibility of programmes, to allow application to different real situations and different sets of data; and

   b. dynamic features in programmes, to include any evolution of the problems and feedback components.

5. From a purely organizational viewpoint, the definition of a sort of "leading group," composed of the scientists participating in the work, would be advisable. It would help the project director for the work, without any interference with the freedom of the individual scientists.

The above statements come from my personal experience and views.

<u>Comments on the IIASA Water Resources Symposium</u>

Myron B. Fiering

1. I certainly accept Kneese's modification to my topic (1) and agree that our study of other systems analyses should be devoted to those that resulted in economic <u>and</u> structural changes.

I also accept Clough's modification, which suggests that we encourage publication, information sharing, and other motivations to broaden the base of response.

2. Speaking in broad terms, IIASA cannot and should not concentrate its Water Resources effort upon an amplification of well-known techniques. To do so would put the Institute into the role of a consulting engineering firm, a job it would do badly.

However, it would be wise for IIASA to encourage the development of modeling techniques by identifying small, didactic models for analytic solution; by noting sensitivities of solutions; by concentrating on systems response as a function of data, objective and constraints. Then, to prevent all participants from doing unrelated work, the whole must be guided by a single application.

In other words, the purpose of the application is to provide a framework within which methodological advances may be made and to assure that all participants work closely enough together to assist and teach each other. It is not, in my conception, primarily to provide a consulting service which is more appropriately done by other institutions. We can help and abet such services, but must not make them our primary function.

3. Regarding the role of peasants and the decrees of Hammurabi, there seems to be a conception that professionalism is equivalent to mathematics and amateurism to everything else. This is absurd; even mathematicians should be able to learn from peasants, and one thing they might learn is that the mathematical grandeur of a problem conceals the fact that the elegant solution, the global optimum, is often not much better than the intuited solution. It is a proper question to ask when this is apt to be so and when it is prudent to require full-blown analysis. I submit that our decision to study past studies will help us answer this.

4. I am already on record as having a strong view about the composition of the water resources group. It should include economists, hydrologists, biologists, aquatic chemists, statisticians, civil engineers, and the necessary mathematical and control theoretic help.

If extraordinary problems arise in mathematics, these can be given to the IIASA methodological specialists or to co-operating Institutes. The emphasis, not exclusively but importantly, must be given to formulating problems correctly (as regards data availability, objective, institutional constraints, etc.). Solution follows.

5. Problems which cut across area lines should be sought. Thermal pollution is an example of a water resource problem derived from, in part, energy considerations.

Thermal pollution arises from the use of water in generating facilities, from industrial cooling processes, from municipal and domestic waste discharges, and from agricultural spreading. It has ecological consequences, but these are poorly known and largely emotionally announced so that it is hard to separate fact from rumor.

Thermal pollution affects rivers, lakes, and even oceans. There may be major changes in evaporation, even in precipitation patterns, as a consequence. It is worthy of our study.

6. The Alpine lakes study is, on first hearing, worthy of further inquiry. The system is small, relatively well contained, appropriate to most participating countries, nearby, and widely thought to be important.

Moreover, we could enter the study early enough to have some impact. We could help "drive" the data collection rather than conversely. We could initiate a program of periodic review of data collection, asking each time if more or fewer data are required, if they are precise enough, or even if we are measuring the right parameters. This is systems analysis at its best: Are we asking the right questions and measuring the right things? I recommend that we pursue this further; a limnologic study would be a nice complement to whatever riverine system we examine.

7. Hypothetical models are not widely useful unless it is clearly understood that they are didactic or that real data will be inserted as they become available. They serve to evaluate the need for certain data -- if the optimal decision is unchanged over a wide range of assumed regimes, the "real" one doesn't matter very much. I would tend to discourage wide use of hypothetical models because they mask the real issues or devolve into teaching exercises (or both).

8. The water resources collection of Harvard's Gordon McKay Library and of MIT should be used as basic reference points for the IIASA library.

Journals should include the usual operations research material plus all back issues (8 years) of the Journal of Water Resources Research and 10 years or so of the Proc of the American Society of Civil Engineers (Hydraulics and Sanitary Engineering Divisions).

Also:

Econometrica, QJE, Australian Journal of Applied Sciences, Biometrika, AER, Econ Journal

9. Of the 8 or 9 themes outlined below, I feel strongly about 1, 2 and 4. I think the core program, supplemented by the Alpine (or similar) work, would cut across all 3 points quite well.

Topics Which IIASA Might Pursue

(1) Study of other systems (models and analyses)

- a) Where have they been applied ?
- b) Have they been built or merely studied ?
- c) Have they made any palpable difference ?
- d) Have they achieved public acceptance ?
- e) Have they fed back into data collection and monitoring systems ?
- f) Have they succeeded or failed ? Why ?
- g) How long did they take to do ? What were the problems ? Were data available ?
- h) Characteristics by which they can be categorized:
  - i) preliminary screening or not
  - ii) programming coordination with known systems
  - iii) simulation or not
  - iv) search and feedback processes used

i) Institutions to effect trades and to make decisions

j) Sensitivity to physical errors, data errors, model errors and approximations, standards, economic criteria, and ideological constraints.

k) Means of division of work because of methodological or operational difficulties.

(2) Data systems

a) What are the objectives of a given set of models ? Why are the data being collected ?

b) What are the constraints ?

c) Which data are already available ? Which are now measured but in need of refinement ?

d) What use can be made of satellites ?

(3) Ocean and near-continental shelf

a) Marine biology and interaction with currents, rivers, estuaries

b) Simple models of ecological processes

c) Role of equilibrium, i.e. why is an ecologically stable environment necessarily desirable ?

d) Food fish

e) Near-shore oil pollution and discharge of solid/liquid wastes.

(4) Demographic Influences

a) Land use planning

b) Development of models for urban growth and limitations.

(5) Geomorphology (application of systems theory to these phenomena, for example, apply control theory to problem of how rivers change course)

(6) <u>The "Zoo"</u> (response of organisms to environmental insult; relative advantages of preventing insults and of repairing damages)

(7) <u>Splitting the pie</u> (an approach to analyses)

a) Start with massive model and require that each individual or small team take a piece of it and make an analytical model

b) Solve with derivatives

i) sensitivity to parameters - data, etc.
ii) sensitivity to objective function
iii) Newton and Lagrange

c) Search for optimum

(8) <u>International catalyst role</u> for IIASA in fields including:

a) Insurance across international boundaries against disasters

b) Legal and institutional problems in weather modification which no existing body can properly handle.

(9) <u>"Flying Squad"</u> (establish a team to teach systems analysis approach at other institutions)

Reflections on the IIASA Water Resources Conference

Allen V. Kneese

I would like once again to call the attention of the staff to the documents distributed at the conference, based upon the panel meeting at the United States National Academy of Sciences. It reflects the views of a group with a large accumulated experience in the application of systems analysis to water resource problems. Having listened to the discussion of the past three days, I feel the suggestions offered there still to be basically sound. I hope the IIASA staff will consider them seriously.

In what follows I will in no way try to represent any opinions other than my own personal ones. My main comments are as follows:

1) Recommendations 1(a) and 1(b) of the above cited NAS panel document should, in my opinion, be the main core of IIASA's water program for, perhaps, the next two years. There appears to be solid agreement on 1(a) and general agreement on 1(b). In addition to the valid points made about the latter in the NAS panel document, another very important one is that it is a way for the Institute to get its feet on the ground on a concrete problem. Without, at this early stage, implying criticism, IIASA is inexperienced and uninformed in the water resource systems area. Water resource systems analysis is only partly a problem of mathematics and statistics, and members of these distinguished professions cannot go far by themselves in this field. IIASA needs to do something like 1(b) in furtherance of its own educational process.

Proper staffing for these core projects consists primarily of members of the systems engineering, chemical, biological, and economics professions.

2) I was persuaded by the arguments of Professor Rabar and others that, in addition to the core projects indicated above, the Institute should involve itself in a new, exiting project. Lake eutrophication seems well worth considering as a topic for this purpose. The problem exists, in more or less extreme form, in the Soviet Union, in the United States, and in most European countries--especially the Alpine ones. It could therefore be studied close to home. Also, a chance exists here to introduce systems concepts early in the development of research and data programs, which is when they

should be introduced. It should be understood, however, that this would likely be a lengthy undertaking. The time horizon of a decade might be appropriate for expecting completed models and quantitative results. However, IIASA might have the opportunity to help structure a highly important area of water resources research and modelling. Attractiveness is added to the project by the apparant interest of OECD in having Institute involvement. I strongly suggest that the staff take a hard look at this area.

3) The idea was put forward that the Danube is an important European river to which IIASA should appropriately give attention. In my opinion, this is correct. But there is no doubt in my mind that it would be a mistake to attempt to launch immediately a full scale systems study of the Danube under the auspices of IIASA. Such a systems study would have no chance of success without a deep commitment on the part of each of the riparian countries tp devote manpower and resources to a highly structured and thoroughly integrated enterprise involving an expenditure of perhaps ten to twenty million dollars. Despite what might be inferred from some of what was said at the meeting, there is no pre-existing set of data which can be handed over to systems analysts for direct insertion into a model. Problems of standardization of data will have to be considered, gaps filled in, and many special studies made. No effort should be made to launch a full scale systems analysis without a careful feasibility study. The major problem is how to organize such a large, highly articulated, multinational enterprise. To my knowledge, this has never been done. In itself, this presents a highly significant and challenging systems problem. IIASA might make an important contribution by adressing this problem as a major first step in a feasibility study.

4) IIASA should, I believe, have a menu of methodological studies in the water resources area which could be done by individuals and small teams on a shorter term basis. One set of such studies is indicated under heading 2 in the NAS panel document.

5) Similarly, IIASA should be prepared to support studies of important components of the larger water resource systems when opportunities arise. Several such studies are suggested under heading 3 of the NAS panel document.

6) The peculiar international status of IIASA puts it in a good position to sponsor conferences on important international water systems problems which it is not itself prepared to study in detail. Some possibilities:

(a) The one discussed during the session was coastal zone management. This is a highly important area in which several large systems studies are at various stages. Some of the main issues were indicated during the discussion, and I will not repeat them here. I would suggest that planning for a conference on this topic be initiated.

(b) "Pollutants from the atmosphere," would, I think, be another suitable topic. Rainout is becoming increasingly recognized as a source of polluting materials in water courses. Important instances have been identified in the United States and in several other countries. Work on this topic is not advanced but is proceeding, and it is a new, exciting subject.

7) My experience and the discussion of the last several days, plus discussion with other water resources professionals, convinces me that the suggestions for staffing in Professor Letov's paper are not appropriate. I do not see any large role for specialized mathematicians and statisticians in the program in the immediate future. The need is for experts in the substantive areas of water resources but with a systems orientation. Such persons are needed to identify the problems and to design the needed systems in the large. They can then call upon more specialized talents in mathematics as needed for particular problems. The leadership role in the project is not appropriately filled by mathematicians.

8) Among the things Professor Raiffa asked us to reflect upon is the Institute library. The plan he outlined seemed suitable, except that I feel the Institute should invest in back issues of a few selected journals. Also, a list should be developed of a few hundred standard books which should be readily available for consultation by the staff at IIASA offices. Some journals I would suggest are:

<u>Water Resources Research</u> - all issues

<u>Journal of the Sanitary Engineering Division of the American Society of Civil Engineering</u> - last 10 years

<u>Journal of the Hydraulics Division ASCE</u> - last 10 years

<u>Natural Resources Journal</u> - last 10 years

<u>American Economics Review</u> - last 10 years

<u>Economic Journal (British)</u> - last 10 years

<u>Operations Research</u> - last 10 years

<u>Institute of Management Sciences Journal</u> - last 10 years

Comments on Papers Presented at the IFAC-IFORS Conference on Systems Approaches to Developing Countries for the IIASA Conference "Complex Use of Water Resources"

A. Nomoto

Drawing from the observations made in the IFAC-IFORS Conference papers and from discussions carried out at the IIASA Conference, I would like to make some remarks, mainly from the point of view of water resource problems in developing countries.

1. The proposal to take the developing countries into account in structuring any project of IIASA was accepted by the IIASA Conference, although it questioned the efficacy of technology transfer. It would be necessary to take great care in order to carry out such transfers effectively.

2. United States colleagues pointed out the desirability of inviting scholars from developing areas. IIASA could perform a valuable educational function. To avoid making this a unilateral transfer of knowledge and a "technology drain," it would be desirable to have these scholars solve problems of their own countries themselves.

3. Water resource problems in developing areas might sometimes be simpler than those in developed areas. Areas may be vast, but bounded and isolated, with abundant resources and low demand. Pollution is often not studied and is frequently still at a low level. However, it would be very advisable to take precautions before the insult occurs.

4. The objective function and constraints in developing areas would be different from those in developed ones. Generally, the supreme goal would be rapid industrialization. National prestige will be more strongly emphasized in young countries than in older countries.

5. The infrastructures of systems will show some delicate differences in each developing area. These would sometimes be of a traditional, administrative, institutional, or educational nature. Systems analysis, it is hoped, will clarify these infrastructures.

Comments on "The Complex Use of Water Resources"

by Prof. Peter Rogers
of Harvard University, Cambridge, Mass.
June 12th - 14th, 1973

The following comments are based upon more than a decade of study and work in the field of Water Resources Planning. The comments fall into five areas of research and development of systems analysis application which I believe have been not adequately treated (or not treated at all) in the context of Water Resource Planning. These five areas are also areas where the Institute could make significant contributions to the field. And, finally, work in these areas would not necessarily preclude making a pilot study on a particular river basin. In order of generality the areas are:

I. Theories of Planning

Most systems analysis studies of water resources start by considering the river basin as the appropriate unit of analysis. This is not necessarily the best or the "correct" unit to use in all cases, or in most cases. Much more attention must be paid to the decisions which are to be made and the decision-makers before the unit of analysis can be selected. In fact, in my own work I am increasingly finding that a "water resource sector" composed of many river basins is the most useful unit of analysis for national water resources policy analyses. Obviously the hierarchical nature of decision making is of fundamental importance here and fits in very nicely with the Institute's work on "multi-level" models. We must be careful to remember that "decomposition" is not just a computational algorithm to enable us to solve large programming problems that we could not otherwise solve, but it is a theory of planning in its own right!

Theories of planning are ultimately theories of society, and it is my belief that an international institute is the ideal location to pursue such types of studies. The availability of comparative data and studies and a staff trained under widely different social systems could make a major contribution to our understanding of how the different planning systems work, how they could or should work, and what is the most appropriate method/system to apply in new applications faced by the international community.

II. Design of Institutions

This is an area closely aligned with the above but dealing with the design of specific institutions to respond to the opportunities provided by new technologies (both hardware and software). For example, what should be the appropriate constitution, voting powers, appropriation power, and regulatory power of a Water Pollution Authority in a river basin or in a region? These types of questions can only be adequately answered by making detailed systems analysis studies of the basin/region and by parametrically varying the institutional arrangements (unfortunately in the past we have always assumed that the institutions for Water Resources Planning were given exogenously).

Another example, and one that is currently of great interest in the developing world, is that of the best form of rural organization to take advantage of investments in water resource developments. Communes, collectives, cooperatives, and individual capitalist farmers have different "profitability" under different natural conditions and different investment schedules. The Institute could certainly throw some light onto which form of organization is more appropriate under which condition.

III. Choice of Technology

Perhaps the crux of most water resources investment planning problems is what type of technology to apply. In the past we (in the West, at least) have always assumed a very restricted choice from among the most advanced technologies. This is, however, catching up with us in two major ways.

The first is in the environmental field where we must now take a careful look at the environmental problems caused by the "technological fix" used to solve another environmental problem. A notorious example of this is the solid waste (sludge) produced by wastewater treatment plants. Another example is the air pollution due to the incineration of solid wastes.

The second field where the choice of technologies is paramount is that of water control for agriculture in the developing countries. There are numerous examples scattered throughout the world where the wrong technology has been suggested for irrigation. In many cases large modern technologies are forced upon societies which are organized in small family farms. This obviously relates to my earlier point about the design of social organizations to cope with technology. In defense of the agencies which have perpetrated these projects, we can say that there are no well-developed case studies or planning studies to which they could turn for guidance and enlightment.

The Institute could make a major contribution to agencies such as The World Bank (IBRD), AID, UNDP, FAO, etc., by providing the detailed studies in this area.

IV. Conflict Resolution Models

Model studies need to be undertaken not only at the international level but also at the national level between regions and even within particular water resource planning agencies. Such studies would be able to take advantage of other work at the Institute on Game Theory, Team Theory, etc. The conflict resolution studies would be particularly helpful in Area II above.

V. Land-Use and Water Resources Development

This is an area of particular concern from environmental considerations. First, it now appears that large amounts of pollution (in some cases the major amount) enter rivers from non-point sources. The control of these non-point sources by land-use planning and development may be the only way to achieve the water quality desired in the stream. Second, most of the people in the world live in coastal zones where the joint control and development of surface and ground water is extremely complex and not well understood. The field of Water Resources is crying out for "halfway decent" methodologies to deal with these problems. Notice that both of these problems entail widening the scope of the analysis to include more than the river basin itself (in the spirit of Area I above).

Summary

I am in no way proposing that studies done in these areas be "think" pieces devoid of empirical content. On the contrary, I believe that studies in these areas can only be carried out by using the full armoury of mathematical techniques available to systems analysts (and by developing more) applied to specific environmental situations. I could envisage a situation where one river basin and region was chosen, and, where one overall model could be used as the basic building block for studies in these five areas. On the other hand, studies from these areas could be made on widely differing projects chosen for their convenient emphasis of one particular area.

IIASA Research Planning Symposium

on

"The Complex Use of Water Resources"

N. Rowntree and C.P. Young

The following notes were prepared immediately after the conference while still in Baden and therefore represent the personal views of the delegates after having taken part in the conference. They do not necessarily represent the views of the Royal Society, London, although it is hoped that they may not be too different.

Situation in the United Kingdom

1. UK organizations involved in water systems studies

   (a) Water Resources Board, Reading Bridge House, Reading, Berks.

   (b) Water Pollution Research Laboratory, Elder Way, Stevenage, Herts.

   (c) Trent River Authority, 206 Derby Road, Nottingham

   (d) Great Ouse River Authority, Great Ouse House, Clarendon Road, Cambridge

   (e) Water Research Association, Ferry Lane, Medmenham, Marlow, Bucks.

   (f) Directorate General of Water Engineering, Department of the Environment, 2 Marsham Street, London, SW1P 3EB

   (g) Local Government Operational Research Unit, Norman House, Kings Road, Reading, Berks.

   (h) Various Universities--

      (i) Cambridge
      (ii) Birmingham
      (iii) Lancaster
      (iv) Newcastle on Tyne
      (v) Southhampton
      and others.

Note: After 1st April 1974 the organizations (a) to (e) will cease to exist, being replaced by a new Central Water Research Centre, Central Water Planning Unit, National Water Council and Regional Water Authorities. Notification will be sent in due course of the adresses of people involved in systems analysis after 1st April 1974.

2. Types of problems investigated in the UK

(a) Planning studies

(i) Pollution in estuaries

(ii) Pollution in rivers

(iii) Simulation of long term national water plan

(b) Operational studies

(i) Multipurpose river flow control using more than one storage basin

(ii) Conjunctive use of surface water and groundwater

(iii) Water distribution systems

(c) Planning and operational studies

(i) Conjunctive use of desalination and conventional water sources

(ii) Inter-river transfers--control of flow and ecological problems

3. List of major studies in the UK

(a) Thames estuary pollution

(b) Tees estuary pollution

(c) Humber estuary pollution

(d) Severn estuary pollution

(e) Mersey estuary pollution

(f) Trent river pollution

(g) Great Ouse river pollution

(h) River Dee flow control and automated data handling system

(i) Thames groundwater project

(j) Great Ouse groundwater project

(k) Shropshire groundwater/River Severn project

(l) Water Research Association desalination report

(m) Water Resources Board/UK Atomic Energy Authority desalination studies

(n) Water Resources Board--national and regional studies involving planning simulations

(o) Water supply networks--Water Research Association and water supply undertakings.

Programme of Work

1. Problems of large scale water systems and the method of approach.

This section is concerned with the report produced by Professor A. Letov and with the possibility of modelling the river Danube discussed at the conference.

The ability to model completely a large, complex water system, having regard also to the overall economy, has for long been the ambition of water managers. In the early 1950's the United Nations produced a report on integrated river basin management which showed the background to the need. The paper by Professor Letov sets out very helpfully the factors which would have to be borne in mind and the techniques involved in a major study such as the river Danube, although of course the question of pollution, which is a crucial one nowadays, was left to be added later.

The desire to achieve such an ambitious target must be tempered by knowledge of the great problems involved and the very real dangers of arriving at incorrect or unacceptable conclusions, particularly in an international, or even inter-regional, system. In the UK considerable sums of money have been spent in the last five years attempting to apply various methods of systems analysis to river basin catchments on a much smaller scale than the Danube and for a variety of purposes. The study of the river Trent looked at pollution problems and cost over £500,000 ($1,290,000). The Great Ouse study of the conjunctive use of groundwater and surface water cost about £200,000 ($516,000). The Dee river regulation studies have so far cost £300,000 ($775,000), and over £100,000 ($258,000) has been spent on the Thames groundwater studies, which are now being implemented. The following notes are therefore made from hard experience, indicating the great difficulties of achieving useful practical results.

(a) The data on which the studies are to be based must be relevant, compatible, and accurate.

(b) The administrative system must be one under which the data can be compulsorily collected and assimilated. (In the UK this was not possible until new water legislation set up a complete licensing system for water users. This problem would seem to be insurmountable at the present time in an international river.)

(c) There are great difficulties in modelling pollution aspects which exercise considerable influence on water use and re-use and hence on the overall availability of supplies.

(d) There is a multitude of sensible alternatives.

(e) There are difficulties in the precise definition of the scope of the systems analysis aspects of the exercise.

(f) The sheer size of the computational exercise and the mental effort involved for accurate supervision, co-ordination and interpretation present a major obstacle to large scale river basin management.

Having pointed out the practical problems of achieving quickly and at reasonable cost a systems analysis of the river Danube or any other major river, we do not mean that the ability to look at large, complex systems of this type should be abandoned. At the present time, efforts should go into the systematic subdivision of the problem and its later re-integration so that available choices can be made apparent and critical factors identified.

The Letov paper is a first essential step in the appreciation of the problem, and it might be useful to continue thought on the form of a still further expanded theoretical model which can then be dissected into typical and essential components for detailed study.

This work would form a background of fundamental long term effort by the Institute, carried out with the modest manpower budget which is available to it and perhaps closely related to the large scale efforts already in being in some countries.

Although such an exercise would not produce results of value in the operational sense for a very long time, it would serve as a backcloth upon which to relate diverse short term activities of the Institute in order to ensure a co-ordinated program of many more modest efforts. Such greater variety may well facilitate the problem of meeting the many varied requirements for water management whether they be national or international.

Such a program will be necessary to demonstrate in the near future the value of the Institute and to ensure the goodwill and ready collaboration of member countries.

Finally, we consider that the suggestion made that some initial effort should be devoted to the examination of past studies is most helpful, provided it is thorough and critical. It will enable the methodology to be evaluated and common problems and gaps in our knowledge to be identified.

2. <u>UK studies which could be examined retrospectively</u>

(a) Trent River Pollution Study

(b) Thames Estuary Pollution Study

(c) River Dee River Flow Control Study

(d) Conjunctive use of surface water and groundwater: River Thames or River Great Ouse

(e) Water Research Association and/or Water Resources Board desalination conjunctive use studies

(f) Water Resources Board planning studies
   (a) National
   (b) Welland and Nene transfers (this was a special case for advanced study in planning).

3. <u>Suggested small projects</u>

In this context the word "small" refers to the cost and the amount of effort involved, bearing in mind that a large area with simple problems may be easier to deal with than a small area analysed in very great detail. The projects should be sub-divided under the following headings:

(a) Planning studies

(b) Operational studies

(c) Studies between water resources and other general subjects to be discussed during the next few months by the Institute, e.g. between water and agriculture, or the procedures for making choices and selecting items of national priority, say between water and roads

(d) Examination of procedures for feasibility studies.

Note: We would not wish to place any priority on subjects for such studies at this stage but consider that a small group should meet together to consider the papers submitted from various countries and draw up a list of priorities, bearing in mind the availability of data and expertise in national organisations and the opportunities for checking the results.

4. References

A list of UK references is being prepared, particularly in connection with the projects referred to above. Copies of some of the relevant papers were handed by Sir Norman Rowntree to Dr. Raiffa at the conference.

IX. SYMPOSIUM RECOMMENDATIONS FOR RESEARCH TOPICS

It seems useful to concentrate the recommendation on research topics, which have been made by the Symposium participants, in written and oral presentations.

I. US National Academy of Sciences - Panel Discussion

1.1 An international comparative analysis of regional case studies and planning enterprises.

1.2 Retrospective re-study of case studies - e.g. Delaware, Vistula, Potomac, Ruhr Rivers - the application of SA in these instances was rudimentary and new policy alternatives can yield methodological improvements.

1.3 IIASA support for a group of methodological studies, including perhaps linkages in models, the disaggregation problem, accuracy of results of disaggregation.

1.4 Determination of the strongest dynamic and stochastic features of the "complex use of water resources" problems and how they may be combined to achieve useful results.

1.5 Consideration of approaches other than the usual optimizing approaches in the face of true uncertainty. Stability, sensitivity and irreversibility become important points of reference in such situations. The problem of decision-making under uncertainty, which characterizes all realistic situations, is an old, well-recognized problem which, so far, has no entirely satisfactory solution.

1.6 Application of optimal control theory to systems operation as well as to planning problems. For example, in operating flood control reservoirs one may wish to find some optimal function of depth and duration of flood waters for scheduling releases.

1.7 Evaluation of the outcomes produced by different approaches to water resources allocation problems, particularly differences between planned societies and those based upon consumer preferences.

1.8 Development of improved dynamic aquatic ecosystem models. Methods of repairing ecological systems after an insult has occurred.

1.9 Study of the linkages of Surface and Ground waters and the problem of their conjunctive use and management.

1.10 Exploration of non-point sources of water pollution.

1.11 Standardization of the data which we need for application of SA to various types of water resources allocation problems.

II. Committee on SA from POLAND

2.1 The theory of stochastic processes and its application to the determination of quantitative availability of water resources, and their temporal and spatial distribution within the system boundaries.

2.2 Methods of rainfall-runoff modeling and hydrometeorological forecasting.

2.3 Development of the methods of synthetic hydrology.

2.4 Study of conjunctive use of surface and ground water resources.

2.5 Reduction of water requirements as new technological processes are developed. Risk elements in assessment of water requirements for the future. Social and ecological nonquantitative dimensions of water resources systems.

2.6 Analysis of all potential investment and non-investment measures for satisfying various water resources requirements.

2.7 Identification of adequate criteria for evaluating the system's social and economic performance.

2.8 Development of relatively simple operational rules for the day-to-day management of complex water systems and each of their elements based on forecasts of changing systems inputs.

III. Italian Water Research Institute

3.1 Identification of surface and underground water hydrology

3.2 Cost and benefit evaluations for new constructions and their operations and for possible variations.

3.3 Interaction of the different development activities connected with water exploitation.

3.4 Evaluation of the impact of water use on social, political, and customary activities.

3.5 Water quality and its influence on the various uses.

3.6 Definition of criteria for the introduction of treatment plants to enable use of initially undesirable water.

IV. Bulgarian National Centre for Cybernetics and Computing Technique

4.1 Long and short range forecasting of floods, high water, and ice as a function of rainfalls, snow thaws, run-off coefficients and controls.

4.2 Forecasting of river water quality as a function of industrial, agricultural, and urban development, and construction of water treatment plants.

4.3 Development of methods of preparing a water economy balance and models for distributing water resources that are acceptable to all countries crossed by the water system.

V. Dr. Allen V. Kneese, USA

5.1 Strong recommendation for pursuit of points 1.1 and 1.2 of the US National Academy of Sciences Panel Discussion proposals.

5.2 Study of the lake eutrophication problem as the first research project. The time horizon for completing the models and for obtaining quantitative results is about a decade.

5.3 Begin research on a topic other than a study of a big river system like the Danube, despite the admitted importance of the problem. There are two reasons for this:

a) IIASA would be involved in an extremely difficult data collection and data processing task; and

b) Successful pursuit of such a project would require a deep commitment from each of the widely divergent countries crossed by the Danube and their close cooperation in a 10-20 million dollar (U.S.) enterprise.

This does not, however, preclude the possibility of conducting a feasibility study on the problem, especially if that study considered the organizational problems.

VI. Prof. Y. Iwasa, Japan

6.1 Unification of the three different approaches to the water resources problem - the viewpoints of engineering, economics, and environmental impact.

6.2 Attention paid to the legal and institutional aspects of water use.

6.3 Study of real water resource situations in the member countries.

6.4 Continuation of the balance between methodological research and applications.

VII. Prof. M. Fiering, USA

7.1 Work on small, didactic, analytically solvable models, noting the sensitivities of solutions and examining system responses to changes in data, objective, and constraints. Having a single application would tie the work together.

7.2 Study the problem of determining when a "full-blown" analysis is required.

7.3 Both the thermal pollution and Alpine lakes studies sound promising. The first cuts across research area lines. The second presents a small, nearby, relatively well contained problem appropriate to most participating countries. Moreover, it affords an opportunity to direct data collection for the study.

VIII. Sir Norman Rowntree and Dr. C.P. Young, U.K.

8.1 It might be useful to continue thought on the form of a still further expanded theoretical model, which can then be dissected into typical and essential components for detailed study. This could form a background for a fundamental long term effort by the Institute.

8.2 Retrospective case studies, if thorough and critical, would enable IIASA to evaluate methodology and to identify common problems and gaps in our knowledge. There are a number of UK studies which could be examined retrospectively, e.g. the Trent River Pollution Study, the River Dee River Flow Control Study, planning studies of the Water Resources board.

8.3 Other useful smaller studies could be planning studies, operational studies, studies of water resources in connection with other general studies, or with procedures for making choices and ordering priorities, examination of procedures for feasibility studies.

IX. The symposium participants collectively suggested the following sub-topics:

9.1 Thermal pollution and waste heat utilization, including interactions with ecological systems.

9.2 The economics of <u>in situ</u> and remote sensing.

9.3 The evaluation of social, political and economic outcomes. How to define objective functions.

9.4 Design of organizations/communications/institutions.

9.5 The various demands for water.

9.6 Comparative studies of national projects.

9.7 Retrospective and historical work on recent studies. Many studies have been done recently but usually with rudimentary use, at best, of SA. If redone with SA, how do the studies improve? What would participants in certain studies change if they had time to do a reanalysis?

9.8 State of the art. Examine recent studies from the point of view of their methodological approach and experimental work, if any.

9.9 Conflict study. How to resolve the conflicts between users at local, national, and international levels. Also, the political constraints which affect implementation of any such analysis. Even if one had an ideal solution, it is unlikely that one could get the appropriate authorities to act on it.

X. CONCLUDING REMARKS BY SYMPOSIUM CHAIRMAN

Mr. Director, Ladies, and Gentlemen,

Let me say a few words about the discussion upon the draft of the Research Programme. I take great pleasure in thanking all of the participants for the extremely fruitful and useful contribution to the discussion. I am very pleased to mention especially the notes ensuing from:

the summary of the US National Academy of Sciences Panel Discussion;

the summary prepared by the Polish Committee on Systems Analysis; and

the documents prepared by the Bulgarian National Center for Cybernetics and Computing Technique and by The Water Research Institute in Rome.

Upon reviewing this material I come to the conclusion that all of these proposals improve or complement the proposed draft of the research programme, rather than overthrow or reject it.

One can notice considerable differences in view-points on questions concerning what to do, how to do it, and what the objectives of this work are. I did not expect unanimity since we are not students of some distinguished teacher, nor is our thinking orientated in one single and same direction. The situation appears very natural and the IIASA should ponder these view-points. Let me mention the most important of them:

the IIASA research group for Water Resources Allocation should include more discipline orientated people rather than only applied mathematicians because of the interdisciplinary character of the problem;

the major emphasis should be on the methodological side of the project rather than on the practical side;

the particular points of methodological interest could be:

(a) the sensitivity of the model structure to the physical errors of its parameter identification,

(b) decision-making in the face of uncertainties,

(c) the prediction of floods or droughts, and

(d) the problem of linkages in models and disaggregation of a LSS.

Attention has been given especially to the selection of the example(s) of the SA methodology application and to the danger which exists, in this connection, of involving IIASA in an arduous task of data collection and data processing. With this in mind, retrospective case studies (Delaware, Ruhr, Potomac, Vistula) have been recommended.

On the other hand, Dr. B. UZUNOV made the suggestion of studying the Danube river basin, basing his argument on the topicality of the allocation of the Danube water resources and on the availability of the relevant data.

All of these ideas will be the subject of the IIASA'S thoughtful consideration and will assist in the preparation of the final draft of the research programme.

Last but not least, I would like to say a few words about the overestimation of mathematics, as though it was entirely responsible for the project. Some of the speakers have mentioned this. It is an attitude which, due to many circumstances, I cannot accept. My colleagues and I share the philosophy that it is not possible to do everything by means of mathematics whilst lacking experience. We are also acquainted with the classical treatment of mathematics as a "millstone which grinds only the substance it receives." We realise that one of the most difficult questions of the project is what it should "receive" in order to obtain good results for the IIASA. This question closely relates to experience, and this is why we need to have the interdisciplinary people, who have accumulated this experience, in the IIASA Research Group. We aim to have these people on the basis of very short visits to the IIASA or on the basis of international aid from the institutions of the IIASA NMO's.

On the other hand, I may talk about the "Complex Use of Water Resources" methods which were employed by peasants in the valleys of the Tiger and Euphrates, under the supervision of King Hammurabi, over 4000 years ago. The experience was most successful and is the first known case in the history of Control Science and Management of an experience based on the application of the idea of the "feed-back control principle." In spite of this, we shall not be going back entirely to the age of King Hammurabi. Our desire is to do our best, using experience already obtained elsewhere, to design a mathematical model adequate to the problem of "Complex Use of Water Resources" and to apply powerful mathematical tools and digital computers to solve it. This is our main goal.

Thank you, once again, for your contributions, and I wish you a good trip home.

XI. APPENDICES

Appendix A:

Research Program

IIASA Project: "Complex Use of Water Resources"

Prepared by A.M. Letov, N.N. Moiseev, P.P. Koryavov, I.P. Belyaev, for discussion during the IIASA conference, June 13-15, 1973, Austria

Introduction

Water resources play an extremely important part in the life of human society. Water is a necessary ingredient of nutrition, a medium for fish life, a source of cheap electrical energy, a necessary component of agriculture and industry, and a means for transportation of people and cargo. Water greatly influences the flora, soil and climate, cleanses cities and towns of pollution, and helps produce oxygen. Fresh water has no substitutes, and without it life on Earth would be impossible.

The total volume of fresh water in the rivers and lakes is, according to hydrological data, not more than 123,000 cubic kilometers. Therefore, the importance of fresh water in human life will only increase in the future, especially if we take into account the exponential growth of population and industry. Nevertheless, as we know from the newspapers and magazines, there are many examples of poor use of these very limited water resources. Thus an extremely important problem of control arises: the problem of the complex use of water resources.

The Continuing Actuality of This Problem

That this problem exists today in critical form is, in fact, the result of human activities. A big community of people settles in the vicinity of large water reservoirs. The people build cities, industrial plants and farms, electrical power stations, and transportation lines. Existing examples show that such construction is always regarded as purely an engineering or a technological problem, where the water is considered as a gift of nature in unlimited quantity and adequate quality. Such an approach to the use of water resources was formed historically and could be justified at the time when power plants and the scale of human activities were much smaller. But now, when giant industrial plants have been built on the banks of many rivers and technological processes use thousands of cubic meters of fresh water daily, this approach has lost its local geographical meaning and no longer corresponds to the interests of society. This is true despite the preventive measures and steps which some countries have undertaken. The old approach needs total alteration.

Complex use of water resources is a very difficult problem of control of a large scale system (LSS) and is the subject of this proposed systems analysis (SA) application. The most important aspects of the problem are:

1. hydrological - identification of a region S and location of the sources and sewers and resources for water control;

2. hydrodynamical - study of stream bed dynamics;

3. geographical - identification of the location of cities and towns, the structure of population and the dynamics of its growth, and the location of industry, electric power stations, agriculture and transportation systems in S;

4. economic - identification of the features of the economic development and water consumption in the present and in the future of cities and towns;

5. ecological - formulation of requirements for ecological equilibrium in S; this equilibrium is necessary for society;

6. social - estimation of the project's possible influence on the life of human communities and formulation of criteria for measuring its social benefit.

There is reason to believe that the water resources problem can best be solved at IIASA because of the international perspective which it can contribute.

a. A large river basin, the object of control, usually touches a number of states (Danube, Tisa, and Nile basins among others); close and honest international collaboration is required for its control.

b. The problem considered here is extremely complicated. Its early solution depends critically upon how efficiently the entire international experience with SA methods is used.

c. The future life of society depends fundamentally upon the means of energy production, upon the skill used in designing and building new cities, upon the successful preservation of ecological equilibrium, and upon the modes of use of water resources. These four aspects present closely connected problems of systems analysis. They should be studied simultaneously, since the successful solution of any of them contributes to the solution of the others.

d. An example illustrates that the complex use of water resources is an essentially international problem, even when the object of control lies within a single state. A man who lives in a city differs from a savage by his understanding that the cleanliness and order in his home depend upon the cleanliness and order in the streets and squares of the city, which belong to everybody. That is why he helps maintain cleanliness and order in the streets and squares of the city. Unfortunately, it is impossible to assert that all states in the world have reached a similar level in understanding their roles and duties in maintaining the cleanliness of the environment--lands, seas, and oceans. There are very often serious disturbances of the ecological "order," such as the distribution of DDT, lead, and radioactive and poisonous matter. These greatly influence the ecological equilibrium in the national basins through water circulation. For example, the amount of lead in the ice in Greenland, located very far from the large industrial centers, has increased 300% <u>every year</u> since 1940 [1].

Research Goals

Our main research goal is the development of systems analysis methods which will permit consideration of all the above aspects of the complex use of water resources and will give to decision makers recommendations which maximize benefit while maintaining ecological equilibrium. The proposed project has two parts:

a) general methodology (theoretical studies), and

b) applications, including study of a particular example of a large river basin (e.g. Tisa, Danube, Dniester).

This document aims to describe the main concepts and program of the research project. The description has been based on a basic principle of SA, which we shall state as follows:

> "A large scale system, as an ordered set of different types of compatible and integrated elements--as equipment, energy sources, materials, money, people and other objects--should operate in time and in space as one well-designed mechanism subject to the feedback control principle."

Thus, for this project, water resources will be considered an important link of the LSS with exactly defined cost and operation functions. The structure of the system is reproduced in Figure 1.

The core of the project closely parallels the ordinary problem of optimal control theory, which is solvable by Pontriagin's Maximum Principle. The parallel includes four of the most important aspects of the problem:

a) identification of the LSS, i.e. design of its mathematical model as the object of control;

b) definition of the initial state of the LSS, its local and global goals;

c) definition of the alternative methods of accomplishing the goals, or the control policies; and

d) formulation of the scalar or vector valued functional which defines the alternatives for accomplishing the goals.

Let us suppose that the object of control is a continental river (CR) supplying fresh water to various users: population centers, industry, energy plants, agriculture, transportation systems. We intend to consider three situations:

1) when the development of the LSS is finished and all users are fixed;

2) when the development of the LSS continues and new fresh water users appear during the studied period of time; and

3) when the development of the LSS is just beginning.

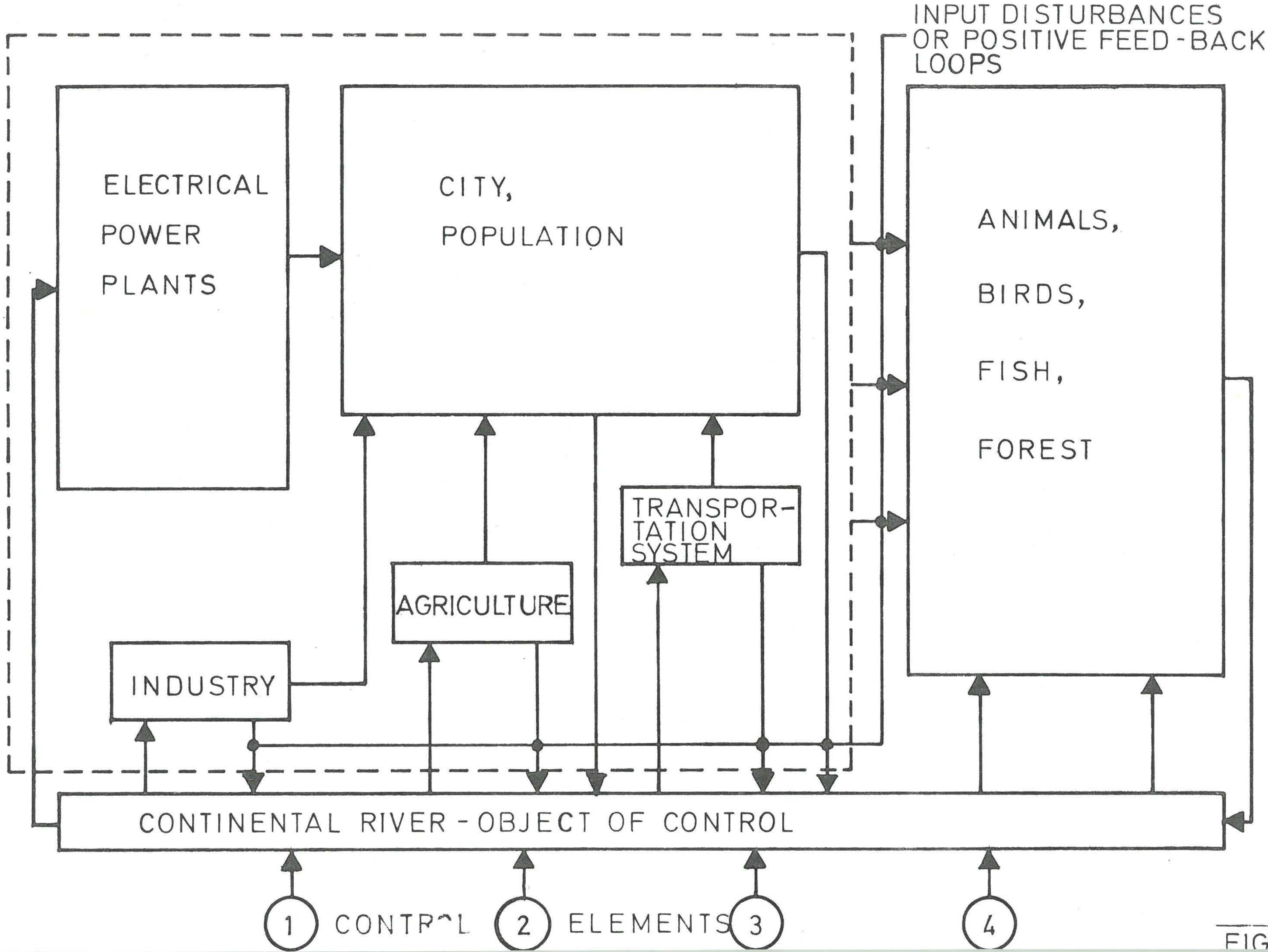
INPUT DISTURBANCES
OR POSITIVE FEED-BACK
LOOPS
ELECTRICAL
POWER
PLANTS
CITY,
POPULATION
ANIMALS,
BIRDS,
FISH,
FOREST
TRANSPOR-
TATION
SYSTEM
AGRICULTURE
INDUSTRY
CONTINENTAL RIVER - OBJECT OF CONTROL
1
2
ELEMENTS
3
4

FIG 1

For all three cases, deterministic models of the LSS and models containing stochastic elements must be designed. In addition, special attention must be given to dangerous situations, for which risk/reliability estimations of the LSS are very important.

The research program must include at least one practical example of application of the general theory. This example will be modelled on a digital computer (DC) not only to demonstrate the effectiveness of the SA concepts, but also to make practical recommendations for carrying out the project.

Identification of the Object of Control

There are no effective methods for identification of the LSS which can bring us to the result at once. But the identification could be done from knowledge of facts about all the aspects mentioned above and many other relevant disciplines. We plan to operate with a model of the complex use of the water resource system; this may first be a mathematical model. To construct the mathematical model in this particular case, we will use operations research theory and other branches of science reflecting each of the various above mentioned aspects of the problem.

We begin with a piece of land, S, which includes:

the continental river itself;

natural or artificially created fresh water reservoirs, which can be treated as flow rate control elements in the LSS; and

all sources of the CR's replenishment, including atmospheric ones, which we shall call the continental river's domain of influence (DI).

Hydrological Aspect

The hydrological aspect of the problem arises in definition of both the fresh water volume W and of all parameters of the replenishment from different sources of the CR and of the control reservoirs.

Hydrodynamical Aspect

The hydrodynamical aspect of the problem is to find some integral parameters of the CR's stream beds and diffusion processes and of the dissolution of different substances in the river.

Geographical Aspect

The geographical aspect begins with the identification of relevant cities and towns, population, industry, agriculture, energy and transportation plants, forests, and recreation areas. Identification of S is reduced to the definition of its main parameters and their variation over time:

- parameters $u_1, u_2, \ldots,$ of admissible outflows as flow control elements, and their upper limits;
- volumes of fresh water consumption $w_1, w_2, \ldots,$ for cities, industry, agriculture, energy and transportation plants;
- costs of fresh water $q_1, q_2, \ldots;$
- volumes of pollutants $p_1, p_2, \ldots,$ and their chemical composition;
- upper limits $\bar{p}_1, \bar{p}_2, \ldots,$ for admissible pollution parameters, which are compatible with a given state of ecological equilibrium;
- upper limits $\bar{u}_1, \bar{u}_2, \ldots,$ for admissible outflows;
- upper limits $\bar{q}_1, \bar{q}_2, \ldots,$ for admissible costs.

Identification of parameters q, p, $\bar{q}$, $\bar{p}$, and $\bar{u}$ depends substantially upon social factors in S: changes over time in the level and structure of the population and their effects upon employment, real wages, education, health care, and climate. Parameters $w_1, w_2, \ldots,$ can be calculated using norms for technological processes employed by each industrial user. Parameters $\bar{p}_1, \bar{p}_2, \ldots,$ are compatible with a given state of ecological equilibrium in S. The last depends substantially upon the forests, flora, and fauna found in S, and upon the chemical composition, flora, and fauna of the CR. In the mathematical model, the set of parameters $\bar{p}_1, \bar{p}_2, \ldots,$ will introduce the state variables constraints.

Identification of the control outflows includes determination of delay times τ_α^β between application of the control elements $u_\alpha(t - \tau_\alpha^\beta)$ at d and their effect at link β of S. A specific difference between the LSS control problem and an ordinary control problem is that the limits $\bar{u}_1, \bar{u}_2, \ldots,$ depend strongly upon weather conditions and upon replenishment from the atmosphere of both control reservoirs and of the CR. For this reason, all these parameters should be identified for use under both normal and disaster conditions.

Economic Aspects - A Simplified Version

The economic aspect of the project is the most difficult and most important aspect. Estimation by mathematical analysis of the economic effectiveness of the LSS is the main subject of this phase in the analysis. We shall review the economics in simple terms to facilitate understanding of the problem, to point out unusual factors, and to explore possible approaches to a mathematical representation.

For this purpose, the LSS will consist of only two elements:

1) agricultural establishments 1,2,...,m; and

2) the continental river.

Pollution is assumed to be non-existent. In this simplified description, we may use a classical operations research model for the optimal land distribution problem.

Agricultural Establishments

We suppose that S contains arable land, pasture land, and forested areas, $a_1, a_2, \ldots, a_m$ square meters. In these areas, there will be 1,2,...,n different products. Let $x_{\alpha\beta}$ be a part of land β which shall be used to grow products α. Parameter $a_{\alpha\beta}$ will be its average productivity. We have the first m + (n•m) + n evident constraints

$$\sum_{\alpha} x_{\alpha\beta} = a_\beta \qquad (\beta = \overline{1,m})$$

$$x_{\alpha\beta} \geq 0 \qquad (\alpha = \overline{1,n})$$

$$y_\beta = \sum_{\beta} a_{\alpha\beta}\, x_{\alpha\beta} \geq \kappa_\alpha \qquad (\alpha = \overline{1,n}) \quad .$$

The new parameters κ_α define the requirements in terms of total products y_α. Furthermore, if the farms have:

$\tilde{w}_1$ efficiency in machinery ,

$\tilde{w}_2$ efficiency in labor force , and

$\tilde{w}_3$ money budgeted for production ,

three other constraints will exist:

$$\sum_\alpha \sum_\beta b_{\alpha\beta}\, x_{\alpha\beta} \leq \tilde{w}_1$$

$$\sum_\alpha \sum_\beta c_{\alpha\beta}\, x_{\alpha\beta} \leq \tilde{w}_2$$

$$\sum_\alpha \sum_\beta d_{\alpha\beta}\, a_{\alpha\beta}\, x_{\alpha\beta} \leq \tilde{w}_3 \quad .$$

The parameters $b_{\alpha\beta}, c_{\alpha\beta}, d_{\alpha\beta}$ are averages for machines, labor, and expenditures of money which produce an average harvest of α products on β land.

Water of the CR

Let $w_{\alpha\beta}$ be the quantity of water which can be provided by irrigation of β land for the production of α product. It is clear that parameter $a_{\alpha\beta}$ will be some function of the $w_{\alpha\beta}$ variable (Figure 2). This function is continuous, unimodal, and has a maximum. It is further evident that parameters $b_{\alpha\beta}, c_{\alpha\beta}, d_{\alpha\beta}$ will be some known functions of variable $w_{\alpha\beta}$. Let $c_{\alpha\beta}$ be the cost of a water unit for β land and product α. In this case, we have a mathematical model of the problem:

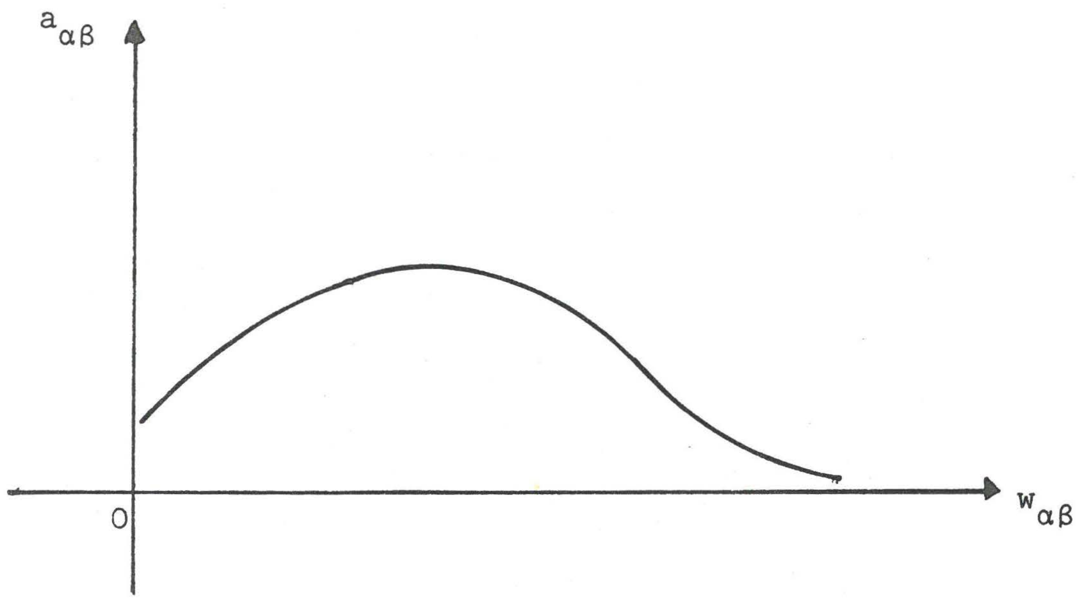

Figure 2

$$\sum_{\alpha} x_{\alpha\beta} = a_{\beta} \qquad (\beta = \overline{1,m})$$

$$x_{\alpha\beta} \geq 0 \qquad (\alpha = \overline{1,n})$$

$$y_{\alpha} = \sum_{\beta} a_{\alpha\beta}(w_{\alpha\beta})\ x_{\alpha\beta} \geq \kappa_{\alpha} \qquad (\alpha = \overline{1,n})$$

$$\sum_{\alpha} \sum_{\beta} b_{\alpha\beta}(w_{\alpha\beta})\ x_{\alpha\beta} \leq \tilde{w}_1$$

$$\sum_{\alpha} \sum_{\beta} c_{\alpha\beta}(w_{\alpha\beta})\ x_{\alpha\beta} \leq \tilde{w}_2$$

$$\sum_{\alpha} \sum_{\beta} d_{\alpha\beta}(w_{\alpha\beta})\ a_{\alpha\beta}(w_{\alpha\beta})\ x_{\alpha\beta} \leq \tilde{w}_3 ,$$

and the functional, which estimates a social benefit of the system,

$$z = \sum u_{\alpha} y_{\alpha} - \sum u_{\alpha}(y_{\alpha} - \kappa_{\alpha})$$
$$- \sum_{\alpha} \sum_{\beta} d_{\alpha\beta}(w_{\alpha\beta})\ a_{\alpha\beta}(w_{\alpha\beta})\ x_{\alpha\beta}$$
$$- \sum_{\alpha} \sum_{\beta} b_{\alpha\beta} w_{\alpha\beta} x_{\alpha\beta} \quad .$$

Here u_{α} is the price of the α product, and we consider it as a control element for providing a maximum z under conditions

$$0 < u_{\alpha} \leq \bar{u}_{\alpha}(w_{\alpha\beta}) \quad .$$

The other features and agricultural measures can be taken into consideration in the same manner. At this point we should indicate at least one new important mathematical element in the problem. In traditional control science continuous and discrete control functions exist separately; we can now face in the LSS control situation the possibility of their unification [2].

Environmental Aspect

Any of the LSS elements--energy, industrial and agricultural plants, towns, cities--is a source of an ecological equilibrium violation. A human being must understand his responsibility for environmental damage caused by industrial, agricultural, or urban development. Society must undertake special measures to improve the environment and to achieve a new, more favorable state of the ecological equilibrium. Great attention should be paid to the problem of protection, reproduction, and increase of fish resources.

There exist at least two methods for mathematically describing ecological problems. Let us denote $\gamma_1, \gamma_2, \ldots, \gamma_3$ the quantities of the various chemical components of artificial fertilizers. The fertilizers increase the average productivity parameters $a_{\alpha\beta}$,

$$a_{\alpha\beta} = a_{\alpha\beta}(\gamma_1, \ldots, {}_s) \quad .$$

In this first approach, if the $\gamma_1, \ldots, \gamma_s$ are the space variables, and $m^{(i)}, \ldots, m_s^{(i)}$ is some set of constant parameters, then the linear function

$$\sum_{j=1}^{s} m_j^{(i)} \gamma_j$$

represents, in the simplest case, the harmful amount of chemical component i falling into the CR with rain and floods. A mathematical constraint describing an ecological aspect of the problem is

$$\sum_{j=1}^{s} m_j^{(i)} \gamma_j \leq \bar{p}_i \ , \qquad i = 1,2,\ldots \quad .$$

The second method is based on an interpretation of the CR as agricultural land. Let us denote the CR's surface area by a_{m+1} square meters, and let $l_1, l_2, \ldots,$ be the average productivity of the CR for fish $z_1, z_2, \ldots$.

Total productivity will be

$$\sum \ (l_k z_k) \ a_{m+1} = U \quad .$$

The parameters $l_1, l_2, \ldots,$ are known functions of the pollutants, as pointed out in Figure 3. Similar mathematical methods can be used to introduce other important products into the model of our LSS.

Social Aspect

The social side of the project includes considerations of population growth, employment, wage benefits, and upper limits for different cost matrices. It includes selection of the project's potential social benefit criteria, or, its performance index. The maximization of social benefit through properly selected criteria will provide a feedback control principle for application to the LSS, and thus decrease the gap which sometimes occurs between planning and actual operation of an LSS.

There are several ways of selecting the criteria. The first is by the formulation of a simple scalar valued criterion of the project's societal profitability. For the second method, we can easily identify a set of scalar valued criteria which reflect the societal profitability of each LSS subsystem. Having introduced a set of weighting coefficients, we can once again form scalar valued criteria. On the other hand, we can formulate vector valued criteria for estimating LSS's social and economic profitability. This last method will present a problem of special scientific and practical interest which can be attacked as part of the research program.

Improvement of the Model

We can enlarge or iterate the model design after completing it for the simplest case. The goal of modification is to introduce innovations into the model, particularly those being considered by regional authorities. Mathematical formalization of these innovations can be done by the methods described above. Further, we must find any new random variables and their associated probability distributions. Infrequent disasters--e.g. drought or excessive water during spring thaw--must be taken into special consideration. The reliability of the LSS is closely related to the cost of the LSS and to the modes of its operation and maintenance.

Goal Definition

Each LSS has its own goal of operation which we classify as a global, or supremal, goal. Each subsystem of the LSS has

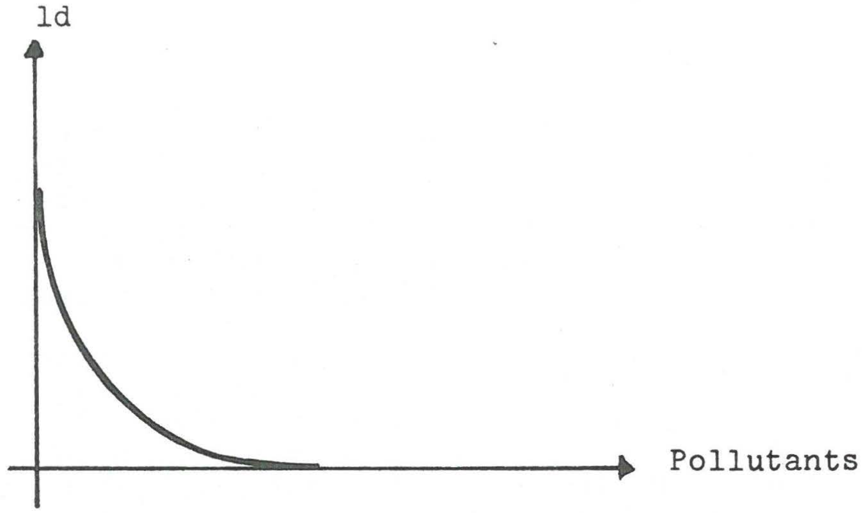

Figure 3

its own goal of operation which we classify as a local, or infimal, goal. We will consider the case where both kinds of goals are coordinated--that is, where the success of any infimal goal and any of the alternative methods for its realization culminate in the success of the supremal goal.

The satisfaction of the water users' demands--industry, agriculture, transportation systems, energy plants, cities, and recreation areas--under existing (or even improved) conditions of ecological equilibrium will be considered the supremal goal of the project. Other important limitations should also be taken into consideration.

Definition of the Alternatives

We have emphasized that definition of the alternatives in the systems analysis problem parallels selection of the admissible control functions in an ordinary problem of optimal control theory. But an important difference appears in the case of the LSS due to the existence of local goals. Let us examine this specific feature of the LSS in more detail.

If i represents the initial industrial production level, and industry authorities plan to increase it twofold, the point f will mark a local goal of this subsystem (Figure 4). The local goal is attainable under existing production methods by doubling water use, arc iaf. But the goal may also be attained by employing new methods which may arise as natural consequences of general scientific and technological progress, arc ibf. This method may even bring a decrease in water use.

Thus, when a means of accomplishing the global goal passes through point i, it may split into many admissible alternatives to reach point f. This specific situation never occurs in ordinary problems of optimal control and must be considered when we define alternative means of accomplishing the supremal goal. This specific feature means that the LSS control problem never will have a single solution.

Control Aspect

The control aspect of the project begins with the following tasks:

- ordering of all subsystems
- establishment of their compatibility
- design of the LSS multilevel systems hierarchy

- determination of the information available and the information needed for control operations and information processing

- coordination of activity between supremal and infimal decision units

- clarification of the sensitivity of problem solutions to different circumstances.

Once the capacities of the control reservoirs are defined, the control aspect provides operational procedures for decision makers to use under all conditions of the subsystems and their admissible environmental behavior.

Modelling

Insofar as the given LSS cannot be treated in a purely analytical manner, its investigation can be implemented with a digital computer (DC). Modelling will clarify the principal LSS quantities, the functional character of their causalities, the possible local feedback control loops, and the influence of time delay elements and their interconnections and sensitivities to different situations. The aims of modelling are:

a) to find all of the LSS admissible trajectory behaviors and the influence of admissible policies;

b) to quantify the effects of all types of disturbances; and

c) to find the best policy for maintaining the LSS.

The modelling can be done by formalization of the LSS model, selection of an appropriate language, and information processing using the DC. Modelling permits estimation of scalar or vector valued criteria and discovery of the LSS optimal control policy.

Development of the Program over Time and Format for Presentation of Results

First Year

Study of the relevant literature

Data collection, especially with respect to the application example selected

Visits from IIASA national member organizations

Preparation of a technical report about the state of the art concerning the water resources problem

Second Year

Identification of the LSS methodology

Data processing and preparation of the example

Report on the mathematical model of the LSS

Third Year

Definition of goals of LSS operation and of alternative means for achieving them

Selection of the LSS social performance criteria

Report on the statement of the research problem

Fourth Year

Modelling of the prepared example with possible iteration of its model and estimation of the social benefit criteria

Report on results of modelling

Fifth Year

Preparation of a monograph on "Complex Use of Water Resources"

Expected Results

We expect the research program to produce the following results:

1. A general methodological statement of the problem including: initial data handling, selection of goals and alternative means of their realization, selection of social performance criteria, and SA methods for researching the problem.

2. Modelling of the example and recommendations on the optimal control policy for its operation. Recommendations of research methods which can consider innovations such as those mentioned in Part V above.

3. A monograph, to be written in the form of a handbook, entitled "Complex Use of Water Resources."

Composition of the Research Group

The limited size of the IIASA staff makes it preferable to form a rather small research team consisting of:

A project leader	1
Mathematicians having considerable experience in control science (or systems analysis)	5
A Mathematician-Probabilist for ½ term	1
An Economist-Sociologist for ½ term	1
Hydrologists	2
Programmers for ½ term	2
Total for full term:	10

It is expected that this team will work closely with other IIASA groups and with other international research institutions concerned with this problem. Appropriate satellites of the group must be organized in national member organizations.

Program Budget Estimate for A Ten-Member Group for Five Years

Salary 10@ $22,000 x 5 years	$ 1,100,000
Travel Expenses for 2 trips @ $4,000 per person	80,000
One 5-Day Conference at IIASA for 30 people @ $200	30,000
Cost of Modelling	60,000
Miscellaneous Materials	30,000
Total	$ 1,300,000

The budgetary cost of the project should be a subject of special interest to the Finance Committee. Special inspection should be given to Item 4.

References

[1] D.H. Meadows, D.L. Meadows, J. Randers, W.W. Behrens. Limits to Growth, A Potomac Associates Book, 1971.

[2] A.M. Letov. The State of Art and Some Perspectives of the Control Theory Development. Automatica and Telemechanica, No. 9, 1972.

Appendix B:

A Concept-Model for Establishing a National Information System for Optimal Management and Utilization of Water Resources in the People's Republic of Bulgaria

The development of industry and agriculture and the rising standard of living of the population require ever larger quantities of water. However, the available water resources in the People's Republic of Bulgaria are not sufficient. The usable water mass amounts to about 160,000 cubic meters per year per square kilometer of this country's territory. Out of this amount, some 64,000 cubic meters per year per square kilometer or 40 percent, are set aside for drinking, industrial, and agricultural needs, while about 108,500 cubic meters per year per square kilometer are used for power generation. Exploitation of the remaining water resources will become ever costlier, with the overall costs exceeding many times the national annual budget. For this reason, the water resources not yet included in the scheme will be added during the next several decades.

Water consumption is increasing rapidly, and some areas are now experiencing sharp water shortages. These water shortages will increase in the future. Meanwhile, the present available water resources are not utilized rationally. Significant amounts of water remain unused for organizational reasons (between 20 and 40 percent for the various branches and water supply systems). Moreover, water resources are continually polluted, which makes their water unsuitable for use. All of this aggravates the water shortages problem. Futhermore, the numerous water consumers have contradicting needs and interests which in many cases must be satisfied from the same water supply. For example, the power utilities require water for power generation throughout the entire year, while the irrigation utilities require storage of water for the irrigation season.

In order to ensure the economical, effective use of water with maximum benefit for the total national economy, it will be necessary to set up a unified, national automated system for complex utilization, management, and pollution control of our national water resources. This system will provide the necessary information for taking correct decisions in forecasting water supplies and water consumption on the one hand, and in planning their distribution under strict utilization controls and anti-pollution measures on the other.

The system aims to provide optimum management and utilization of water resources in Bulgaria and to ensure their protection from pollution and exhaustion. This will be achieved through full and accurate data acquisition at all levels about the existing conditions and about the dynamics of the operational processes. This will be done using scientifically-justified economic and mathematical forecasting and planning with extensive use of modern technical means for complex automation and dispatching of processes and for computerized data processing.

The system will function according to the block-diagram shown in Fig. 1. At certain periods the tactical tasks will be outlined, as well as the programs for their implementation and the structural units by which these programs will be realized. The operative tasks are also outlined. The information acquired will make it clear whether the existing conditions are in line with the tactical instructions and norms. If the necessity arises to correct existing conditions to conform with the tactical instructions and norms, several alternatives are worked out and the optimum decision is chosen. Then the operative control unit sends a command to the control board. This is followed by information about the means of realization and about the results. The information obtained is then processed in order to evaluate the economic effect of the decision taken.

The national automated information system for the complex utilization and management of water resources consists of six branch subsystems (Fig. 2). These include a subsystem for hydrometeorological information distribution, for supervision subsystems for control of complex water economic projects, for pollution control, for water-utilization subsystems for hydroelectric power generation, for irrigation, and for domestic and industrial water supplies.

The aim of the system must be strategically justified and coordinated with the general national goals and strategies. The respective methods for accomplishing the task should be in line with the strategy adopted for the overall economic development of the country. The country's general strategy includes maximally meeting the constantly increasing needs of the population. Fulfillment of this goal requires a high degree of automation and the application of electronic devices and cybernetics in the management of production processes. These should be implemented step by step depending on the level of technical development and industrial capabilities of the country. Setting up the system for complex

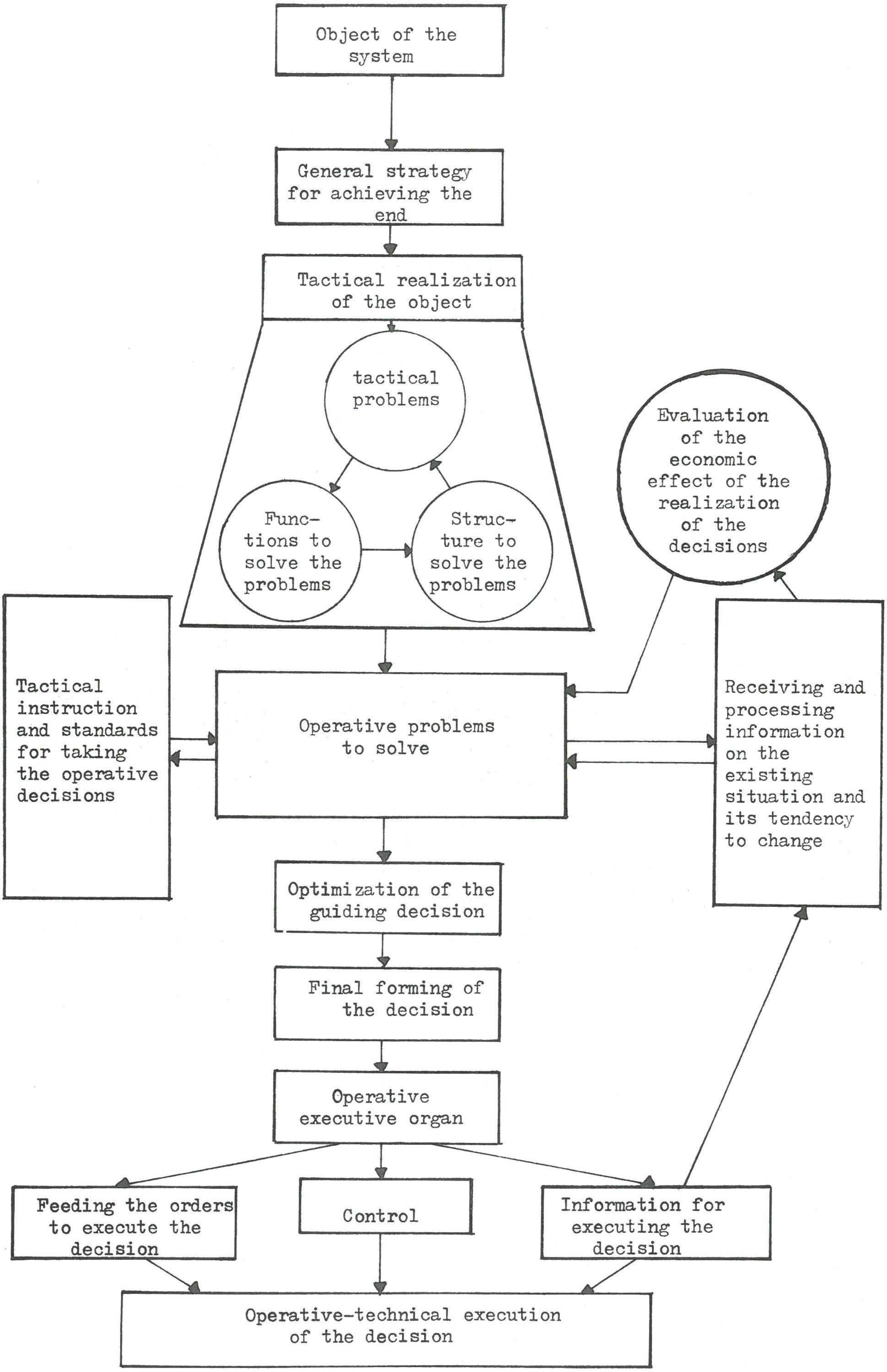
Object of the system
General strategy for achieving the end
Tactical realization of the object
tactical problems
Func-tions to solve the problems
Struc-ture to solve the problems
Evaluation of the economic effect of the realization of the decisions
Tactical instruction and standards for taking the operative decisions
Operative problems to solve
Receiving and processing information on the existing situation and its tendency to change
Optimization of the guiding decision
Final forming of the decision
Operative executive organ
Feeding the orders to execute the decision
Control
Information for executing the decision
Operative-technical execution of the decision

Figure 1

Scheme of

The National Automatic System for Optimal Utilization and Management of Water Resources

in Bulgaria

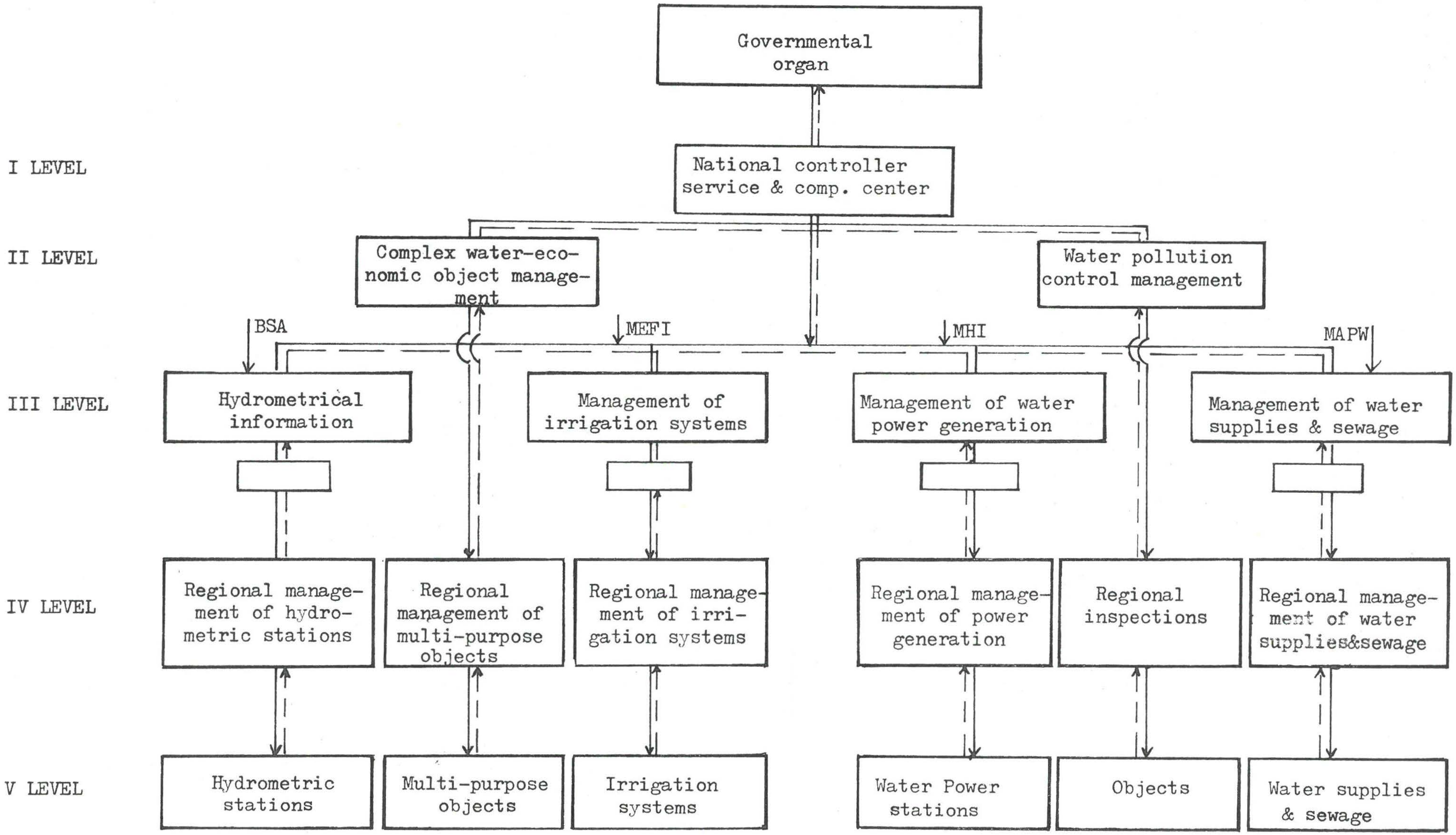

Figure 2

use and management of water resources as a unified, automated information system corresponds fully to the general trend of economic and political development in this country. It is envisaged that system automation be done in stages depending on the national industrial capacity and on imports from abroad.

According to the general block-diagram for management, Fig. 2, the branch subsystems are controlled relatively independently with their overall guidance subordinated to the guidance of the unified management system. The information system is built on the principle of the two-way link: information is sent upward about the state and dynamics of the processes, while information is transmitted downward in connection with management actions.

The basic organizational principles of the national automated system for the complex use and management of water resources can be expressed as unification of the control elements of all individual branches. To accomplish this, the matrix method of modelling is employed.

For the national automated system, a four-dimensional matrix model can be used to generalize and unify all activities connected with the complex and optimum use of the water resources. Fig. 3 shows in general form the four-dimensional matrix model summarizing the system's complex activities. On the abscissa are entered the unified types of activities which apply to each branch: a) capital investments, b) research, c) design, d) basic funds, and e) exploitation of the water resources. On the ordinate are entered the unified management elements pertaining to each type of activity individually: 1) forecasting and perspective planning, 2) annual planning and contacting, 3) operative control and realization, 4) financial and progress reports, and 5) evaluation of the economic effect of the activities.

On the applicable axes the management levels are located as follows: Level I) control of the system for optimum use of water resources by a national dispatching office; Level II) supra-departmental organs dealing with water distribution and water pollution control; Level III) administrations, amalgamations, and directorates subordinate to the ministries and to users of water; Level IV) regional and district offices, water-using systems and control services; and Level V) control of projects and sections. However, the existence of all these activities is not mandatory for each level. Still, the existence of a certain type of activity requires the application of all principles (elements) of management.

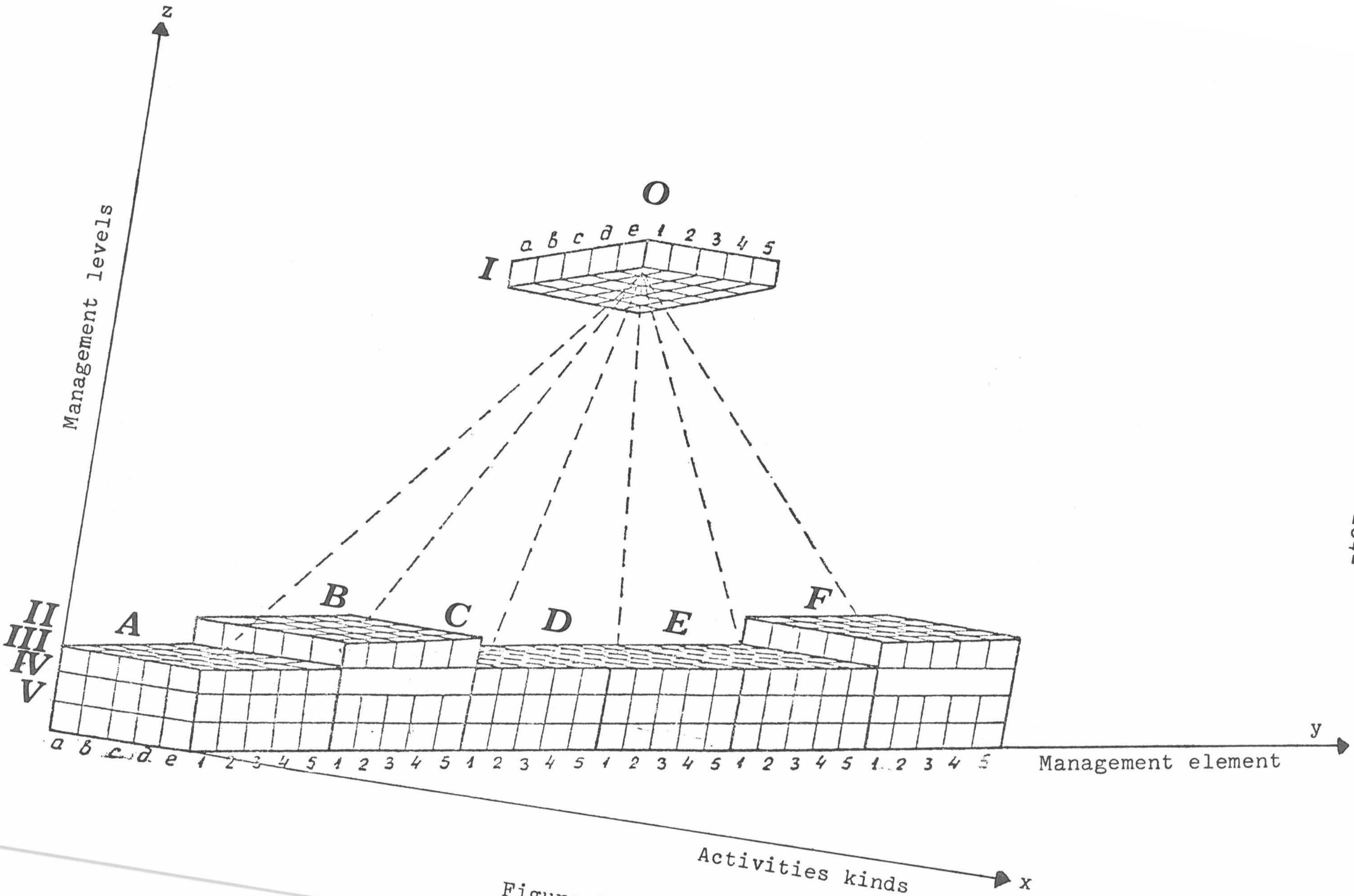
z
Management levels
O
a b c d e 1 2 3 4 5
I
II
III
IV
V
A
B
C
D
E
F
y
Management element
Activities kinds
x

Figure 3

The full scope of activities of each branch of the subsystems can be outlined by means of a three-dimensional matrix model. The fourth dimension of the four-dimensional matrix model is expressed by successive ordering along the ordinate of the three-dimensional matrix models obtained for each subsystem. They are ordered according to the branches which mark their relationship to the three-dimensional matrix model unifying them on the national management level of the system. The individual subsystems are as follows: A) hydrometeorological information, B) administration of complex water economy projects, C) administration of water utilization in the irrigation systems, D) administration of water utilization for power generation by water power stations, E) administration of water utilization for domestic and industrial water supplies, and F) inspectorate for water pollution control.

On this principle certain generalizations, unifications, and standardizations of management activities were made according to types of work, levels of management, and branches. This permits the creation of a task classifier from elements (cubes) of the matrix model. One also obtains the necessary information for the solution of the tasks and for presolution norms and programs for data processing.

In outline, an example of the general contents of an element of the four-dimensional matrix model, Fig. 2, would be as follows:

d-B-1-III - Forecasting and perspective planning of water use by irrigation systems on the level of the Irrigation Systems State Economic Amalgamation.

<u>Tasks</u>:

1. Determination of water needs

2. Determination of area of the lands under irrigation

3. Forecasting improvement of the efficiency of the water distribution network

4. Forecasting the degree to which water needs are met

5. Forecasting dispatching activities

6. Forecasting personnel requirements, qualifications, and conditions of work.

Necessary information:

1. Forecast of climatic factors
2. Data about water consumption by various crops
3. Data about crop structure and the lands under irrigation
4. Information about the state of equipment and organization of labor
5. Data about the available water resources
6. Information about past dispatching activities
7. Information about malfunctions of equipment and of the system
8. Research data about the methodology for water requirements forecasting and dispatching activities
9. Information about personnel needed, their qualifications, and conditions of work.

Norms and programs:

1. On water requirements forecasting
2. On the optimal degree of meeting water requirements
3. On forecasting the efficiency of the irrigation system
4. On optimizing the dispatching activities
5. On forecasting personnel needed, their qualifications, and conditions of work.

The remaining elements of the four-dimensional matrix method are developed along the same lines. The type, volume, and frequency of data acquisition and the ways of processing it for each task are defined in detail, and the input and output data files for each of the programs are compiled. On the basis of the input and output data files, organograms are developed showing the flow of information among the various elements of the matrix model.

The structural units should be formed according to the kinds of activity and levels of management. All principles (elements) of management should find their place in each structural unit. Separate units should be formed for the different types of activities. Within the framework of a given level, several units may be combined according to the types of activities. When forming the structural units, the following organizational principles should be observed:

1. Principle of one-man management. Each structural unit is controlled by one higher-ranking unit only.

2. Principle of selection. Each unit performs strictly defined work which in no way is parallelled by the work of other units.

3. Principle of pyramidal hierarchy. Each higher-ranking unit in the hierarchic system controls between two and seven units.

4. Principle of hierarchic relations. The relations among the various units are based on the hierarchic system of management only. They do not communicate directly without the participation of a higher-ranking unit.

The internal structural units or structural elements of which each larger structural unit consists should conform to management principles or to each element of the four-dimensional model of the information system. All information coming in from the units of individual subsystems and exchanged among the administrations of the subsystems and the central administration of the system can be unified and standardized into 40 types of information. For example, observation and control of the "water level" element occurs in all branch subsystems. This also holds for many other elements of information. A total of 22 types of devices were developed for acquiring the information thus unified. They were completed and combined into 20 complexes of devices for data acquisition, transmission, and processing which cover all activities of the subsystems and the entire information system. An example of information exchange among the national administrations of the subsystems and the central information system is shown in Fig. 4. Each type of information is designated by an Arabic numeral. The diagram clearly shows the path of each type of information among the subsystems on the one hand, and among the subsystem administrations and the central administration of the system on the other.

The studies made reveal that a total of 15 factors have direct bearing on the alternatives for creating the structural

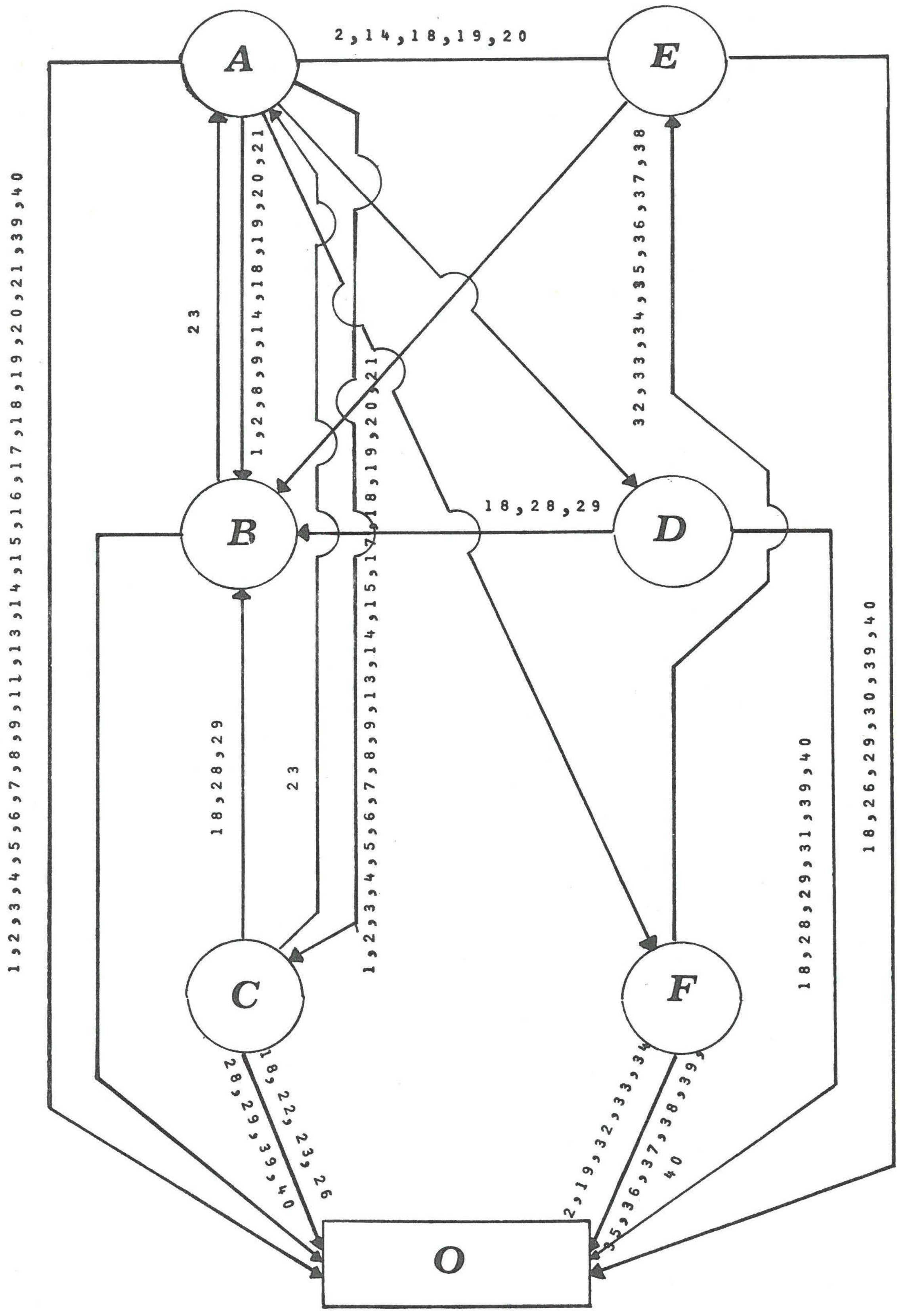
A
B
C
D
E
F
O
2,14,18,19,20
23
1,2,8,9,14,18,19,20,21
1,2,3,4,5,6,7,8,9,11,13,14,15,16,17,18,19,20,21,39,40
32,33,34,35,36,37,38
18,28,29
18,28,29
23
1,2,3,4,5,6,7,8,9,13,14,15,17,18,19,20,21
18,28,29,31,39,40
18,26,29,30,39,40
28,29,39,40
18,22,23,26
2,19,32,33,34
35,36,37,38,39,
40

Figure 4

and functional model of the system: some affect the structure directly; some affect the volume and frequency of data acquisition and transfer; others affect the degree of automation of the activities; and still others, the structure of the data flow. It is technically impossible to solve all the possible variants as they number more than fourteen million. For this reason the variants were grouped on the basis of the following generalizing factors:

1. Hierarchy of data acquisition and transfer. This corresponds to the optimal hierarchy of management and aims at serving it best. It defines to a large extent the location of the information centers, the means of primary processing of data, and the distance between the primary, dispatching, and main dispatching centers.

2. Frequency of transfer (acquisition) of information in the primary information centers. This defines the volume of information per twenty-four hour period and affects significantly the choice of means for data processing and transfer.

3. Frequency of data transfer from the field center to the systematizing and main dispatching centers.

4. Degree of automation of the data acquisition system. This covers the type and volume of information and the number of centers which supply it.

5. Degree of automation of data processing. This influences the operations required for processing a given volume of information.

6. Degree of automation of the system for data acquisition and transfer. This influences the communication links. It is influenced by the type and volume of information, by the number of factors, by the distance to the information centers, and by their number and location.

The above items cover with sufficient accuracy all factors influencing the set-up of the system.

In the studies made in Bulgaria, the optimal periodicity of the basic portion of the operative information was determined; the latter constitutes over 90 percent of the total volume of information. Alternative solutions are suggested for determining the hierarchy for receiving and trnasmitting data individually for all subsystems. By this means the types of information, the number of regions of the main centers, etc., are defined.

The data acquisition system can be automated to three levels: visual, semi-automatic, and automatic. In the case of the visual variant, the investigations are made by means of devices. However, reading is done visually. The semi-automatic variant provides for automatic reading of only part of the information. In the automatic variant, data from the sensors in the primary information centers are fed directly into the next higher-ranking unit by means of analog-to-digital transducers with terminals. There are three modes for adoption of the automated data system: manually, with ELKA calculator; with a computer without an automatic data input; and with a rented computer through terminal with or without operator interference. Various alternatives were developed for the communication links: forms sent by post, punched or magnetic tape sent by post, and communication channels using telephone, telex, terminal.

The actual costs of the equipment and devices were used. This permitted accurate analysis of the influence of the various factors in setting-up the automated system, obtaining the real costs of the automated system for the management of the water resources and determination of the economic characteristics and the expected economic effect. All calculations were done on a computer.

The block-diagram of the algorithm of the target function was made with the intention of printing, as an end result, the criteria values for the purposes of comparison. To permit comparison, analysis of the evaluation of results was done by the same unified criteria. The comparison was done first by subsystems. A comparison was then made to select the optimal variant when all subsystems are in operation. In this case, the stages of automation are different when optimizing the variants of the different subsystems and the intervals of data transfer. It proved expedient for one computing center to process all information and to use the existing communication links of one subsystem for all remaining subsystems when locating the measuring stations at the respective sites.

Development of the concept and four-dimensional matrix model of a system for complex and optimal use, management and pollution control of water resources in the People's Republic of Bulgaria proved that the system is entrusted with a series of management activities. These are linked not only to the various branches of the national economy but also linked to tasks of other nationally important automatic systems.

From analysis of the programs for the exploitation of water resources and from the unification of the elements for control on different levels according to the matrix model, it becomes clear that about 80 percent of the total volume of the tasks to be solved are of the second type--i.e. data processing--and only about 20 percent are of the first type--i.e. multivariate optimization tasks. Applying the unified task classifier, a list was made of the problems and programs for data processing in the exploitation of water resources according to the elements of management levels. The frequency of use of each program was determined (annually, semi-annually, quarterly, monthly, every ten days or three times daily). Also determined were the time in minutes needed for solving each program, the total volume of data flow for the whole country, and the number of signs, and on this basis, the type of computers to be installed in the computing center.

On the basis of the structural and functional model it was decided to work out a preliminary report on a system for complex and optimal utilization and management of the water resources in Bulgaria. The section dealing with the exploitation of complex water economy projects is already completed. Completed preliminary reports about the various branch subsystems are forthcoming.

The first stage for realizing the system will be the setting-up of an experimental system in the area of the Iskar river according to requirements of the optimal variant of the structural and functional model. This station will supply information about all eventual shortcomings in the design, in the structures, and in the utilization of the various pieces of equipment and means for data acquisition, transmission, and processing. Meanwhile a unified system of information will be introduced after 1973. All water users in the country who have permits to use water will be requested to send in the necessary information twice a year. For this, they will fill out and mail in special forms. The intervals for submitting this information will gradually be shortened.

In the first stage, simultaneously with the setting-up of the experimental area, the system's computing center will be put into test operation. At first, it will process primary information on a national level. After establishment of the experimental area, the computing center will also process data from there. The experimental area must be set up before the end of 1975. It will be opened in 1976. On the basis of data received from the experimental area the system will then be introduced into other areas. The system will be completed by the end of 1980. The third stage covers the test operation of the entire system and will continue until 1985. After that year the planned annual effect of the system operation must be ascertained.

According to preliminary estimates, the total economic effect from the introduction of the system for complex and optimal utilization and management of the water resources in the People's Republic of Bulgaria will amount to 125,000,000 Leva with a minimum term of cost redemption.

Authorities in Bulgaria dealing with the problem include:

- Leading authority: Center for Science and Research at the Ministry of Forests and Environment Protection

- Back-up authorities: Institute for Technical Cybernetics at the Bulgarian Academy of Sciences, Institute for Automation in Industry, Institute for Cybernetics in Construction, Institute for Water Problems, Hydrology and Meteorology at the Bulgarian Academy of Sciences.

Personnel employed and their training:	86 specialists
- specialists on the complex utilization of water resources	29
- specialists on automation of processes	19
- specialists on systems analysis and process management	18
- economists	8
- mathematicians	8
- chemists	4

Conclusion

The management and utilization of water resources in the People's Republic of Bulgaria does not differ from that in the rest of Europe. Most European countries experience sharp water resource shortages which will increase in the future. An important problem in all countries is water pollution control. Water is used for various purposes: irrigation, domestic and industrial water supply, power generation, river transport, and recreation. In the People's Republic of Bulgaria studies have been made and plans have been developed for the complex and optimal utilization and management of water resources on a national scale. This will be done by mathematical and economic modelling, systems analysis, and computers. On the basis of this work, it will continue applying the wide-range studies made by IIASA.

Appendix C-Part 1

The "Tiber Research"

Study for Planning and Management of Water Resources in a Large River Basin

Italy

A few years ago, the "Water Research Institute" started a research project aimed at creating methodologies appropriate for the study of integrated utilization of the resources in a large basin. With this work, the Institute proposes moreover to make known to the people in Italy who will have responsibility for water management the most suitable techniques for solving the complicated problems of utilization of water resources related to the prospective social and economical development in Italy. From the organizational point of view, the Institute cooperates with groups interested in and in charge of the utilization of water. For the application of these studies, the Institute has chosen, as an example, the Tiber river basin.

The reasons for this choice are many:

1) The catchment area is large enough and does not present excessive complexities; in fact if larger Italian basins (such as Adige or Po) had been chosen, there would certainly have been greater difficulties because the elements to be examined would be more numerous. On the other hand if smaller basins had been chosen, the study would probably not have been representative enough.

2) The water of the Tiber and its tributaries is utilized for numerous purposes so that the basin under examination makes a very appropriate example of the proposed aim.

3) Along the banks of the Tiber and its tributaries, many industrial complexes and urban communities are springing up, so that it is possible to evaluate more accurately the influence on the problem of the social, economical, and political elements.

4) In the basin there are some important sites of great interest from the historical, scenic, and cultural point of view, and it is very necessary to preserve these from any damage caused by irrational use of water.

Therefore, the most important aspect of this study is neither hydrological nor hydraulic. In fact, vast works of river hydraulics have been carried out on the Tiber so that with the contribution of the available storage in the hydro-electric reservoirs, the danger of flooding seems to be averted. The last damage caused by a flood was in the year 1937, when many of the now existing reservoirs had not yet been built.

The evaluation of economical, political and social elements connected with water management is much more important. In the basin some industrial complexes are in operation (in the Perugia, Tivoli, Orte, Terni, and other areas), and considerable developments are predicted for industries with a high technological level (pharmaceutical, food, electronics). There are also chemical and iron and steel complexes (at Terni). Technologically advanced industrial complexes generally require small quantities of water, but are very demanding with regard to quality. The hydro-electric industry is very important.In the basin there are numerous plants inter-connected hydraulically in order to produce high quality energy. Some plants regulate the frequency. Electric energy, nevertheless, must be considered to a large extent independant of the conditions of the basin itself in that the whole Italian electricity system is completely inter-connected throughout the country.

As it is known, the Tiber basin has an area of 17.000 Km^2; the water flows on various types of soils and the maximum altitude of the basin is 2487 m above the sea level. The length of the main water course is 405 km. There are numerous tributaries, many of which have torrential behaviour; some, however, have a constant flowrate whose maximum may reach the value of some tens of m^3/s. The monthly flow of the river, at the mouth, oscillates between a minimum of about 60 m^3/s and a maximum of about 2700 m^3/s. The highest registered flow has been about 3300 m^3/s.

As in many other Italian regions, the quality of the water in the Tiber river basin is poor, especially downstream from the biggest municipal communities, like Rome. Results of a survey show very high values of pollutants. Interaction between pollution parameters and natural factors, e.g. climate, pick-flow, time of operation and so on, have also been pointed out.

Some mathematical models are under construction. They will represent the behaviour of pollutants in the stream to accord with the information given by field measurements. Such models shall cope with the following peculiarities:

a) The number of discharges is very high, and the discharging points are almost continuously distributed along the river embankments.

b) The interrelation with the hydrological terms ought to be determined by including some statistical evaluation.

In accordance with the trends and objectives pursued up until a few years ago, the use of water for hydroelectric power has been accorded primary importance in the Italian catchment areas. Now this use has been the first to suffer from the limitations imposed by other uses which are becoming more and more important.

The first series of limitations is imposed by the needs of flood control. The Ministry of Public Works, which is now the principal authority responsible for water management, has obliged the Electricity Board (ENEL) to keep the maximum level in the reservoir below a certain predeterminated value. In mathematical terms this corresponds to an "upper bound," in the form

$$V_j \leq VH_j \quad ,$$

meaning that the stored volume, at a time j, shall not exceed the seasonal limit VH_j corresponding to the predetermined level in the same season. The upper bound is evaluated in a prudent manner after a very rough hydrological calculation.

The most convenient flood storage capacity might be calculated after introducing some appropriate short-time hydrological input. A simulation model is available, based on the continuity equation applied to the reservoir, i.e.

$$INP_j + V_{j-1} - V_j - KP_j - X_j = 0 \quad ,$$

in which the variables are defined as follows:

INP_j = the hydrological input to the reservoir during period j ;

V_{j-1}, V_j = volume of the reservoir respectively at the beginning and at the end of period j ;

P_j = total power produced at the plant in the period j ;

X_j = water quantity spilled at the period j ; and

K = factor converting power unit into water quantity .

The model can be used both with historical and synthetic hydrological input, as well as in either a deterministic or a probabilistic manner.

A second order of limitations is imposed by the need to maintain the water level immediately downstream from the high dam that forms the reservoir. It is very common in Italian hydroelectric plants to locate the power station at a considerable distance downstream from the dam, with the aim of increasing the available head and of decreasing the effect of fluctuation in the reservoir. Shortage of water in river bed between the dam and the section in which water is returned from the power station is a relevant actual situation. Subtraction of water from a river can last for seasons, especially in the warmer months which are often characterized by a very poor natural runoff. All the aquatic life can be seriously affected. Within this framework a certain amount of water from the reservoir ought to be spilled in order to restore the natural living conditions.

The same simulation model is also useful for providing an evaluation of the economical impact of the upper bound to give the reduction of power in terms of water discharge and, therefore, in terms of the reduced kwh at the market price.

Although public opinion is beginning to feel the importance of the "ecological" use of water, its mathematical evaluation is nevertheless difficult to achieve. From a purely technical viewpoint the effect of maintaining the water level throughout the river can be evaluated only in the operation and maintenance of gates, sluices, and spilling works.

The calculation of the corresponding benefit lies essentially in non-tangible considerations, such as the of the basin for fishing and bathing or simply for its natural beauties. In the Tiber River basin, a typical example is that of the famous Marmore Falls, that oblige the Electricity Board to spill into the natural stream a constant value of 20 m /s every Sunday and vacation day. Other considerations concern the local agriculture, which even if it has no irrigation scheme, can be affected by the existence of a certain level in the vicinity which can have a regulating effect on the surrounding underground water.

When the reservoirs were built, the possibility of using them for recreational purposes was scarcely considered. Now however, this is becoming more and more important in order to meet an increasing demand for touristic facilities for more people.

The effect of recreational activity on reservoir management lies primarily in the maintenance of the water level above a predetermined value, in order to provide enough water for boating, swimming, and fishing. Furthermore, the level variation should be kept to a minimum in order to permit a constant use of such devices as piers, ladders, and moorings. Reduced variation in the water level is also useful for the conservation of the natural amenities of the countryside. It helps the prevention of landslides and the growth of aquatic plants and weeds. These rot when they are above the surface of the water and cause unpleasant odors which are aesthetically undesirable. Because of these considerations another reduction of the existing reservoir capacity is introduced. This can be expressed as a lower bound

$$V_j \geq VL_j \quad .$$

The term VL_j can vary according to the season. It is expected to be higher during the summer holidays.

In the Appenine regions, as well as throughout the country, the demand for irrigation is particularly urgent in summer. This introduces another term A_j in the continuity equation for the reservoir

$$INP_j + V_j - V_{j-1} - KP_j - X_j - A_j = 0 \quad ,$$

which means a further reduction of water available for electricity. Simulation models can also give an evaluation of both the technical and economical effects, relevant for reservoir management, of releasing water for irrigation. The same applies for the industrial and domestic water supply since these uses occur mainly in the plain, far from the reservoirs.

All these forms of utilization require a large amount of water in the lower parts of the river. The effect on the reservoir can be considered in terms of the release of more water towards the natural downstream reaches. Pollutants and waste discharges affect the problem in a similar way, i.e. they require maintenance of the water above a certain level in order to facilitate dilution phenomena and natural pollution abatement. Simulation procedures (using, for example, the Streeter and Phelps' model or models concerning the propagation of pollutants, chemicals, and temperature) can help to provide information, particularly valid for evaluation of the most appropriate management rules. The degree of pollutants at a certain river cross section can also be evaluated, if the conditions existing at an upstream waste discharging section are known.

Information obtained by using the above-mentioned procedures are also useful to set appropriate lower bounds in the river reaches or, at least in some predetermined control section, in the form

$$X_j \geq XL_j \quad ,$$

where XL_j is a seasonal value.

In some cross sections of the rivers, especially in those located immediately downstream from the waste discharging points, a very large amount of water can be necessary to dilute a large polluting load. Therefore, the XL_j lower bound might reach high values, mainly during the dry season, which would mean a further demand for water from the reservoir and further reduction in power production. An alternative solution would be the installation of advanced treatment plants able to reduce the amount of pollutants to an acceptable "standard."

Use of water for irrigation, conservation of amenities, industrial and urban supply, and natural abatement of pollutant appears therefore as the competitive withdrawals of water from the same reaches of the river, in the flatter area downstream from the reservoirs. These reaches of the river are called upon to assure the necessary amount of water, thus failing in their primary purpose: the production of electricity.

The assessment of the most appropriate role for each of the above uses, including power production, can be done using optimization models. The objective function would have the following form:

$$\text{maxim.} \sum_j \left[\sum_m c_m k_m P_{mj} + \sum_l c_l A_{lj} + \sum_r c_r F_{rj} + \sum_k c_k WIN_{kj} + \sum_n c_n R_{nj} + \sum_h c_h WS_{hj} \right] ,$$

in which the variables are defined as follows:

P_{mj} = power production at the turbine m during period j ;

A_{lj} = target value (in water unit) of agricultural at district l, during period j ;

F_{rj} = storage value for flood control at reservoir r during period j ;

WIN_{kj} = target value (in water unit) to industry K, during period j ;

R_{nj} = target value in water unit to urban area h ;

c_m = "weight" for power production ;

c_l = "weight" for irrigation ;

c_r = "weight" for flood control ;

c_k = "weight" for industrial water supply ;

c_n = "weight" for recreation ;

c_h = "weight" for drinking water ; and

k = the factor to convert power unit into water unit at the plant m .

The model's variables are:

V_{rj} = storage of reservoir r at the end of period j ;

X_{ij} = quantity of water flowing through a river reach designated i during period j ;

Y_{ij} = quantity of water flowing through artificial penstock or canal i during period j ; and

INP_{qj} = hydrological input to cross section (or "node") q during period j .

The evaluation of the "weights," which may be considered independent of time, shall be performed throughout appropriate investigation of the characteristics of each utilization, to accord with the above requirements.

Appendix C - Part 2:

ENEL's Interest and Activities in the Application of Systems Analysis in Complex Use of Water Resources

Italy

Utilization of water for multiple purposes is a matter that has always interested ENEL--one of the main users of the water resources. It has become of special importance in recent years [1],[2], [3] because of the increased interest in using water for purposes other than power generation. This interest is a result of the growing population, industry and tourism. It is also because many of the new possible hydro stations are economically justified today only if associated with other forms of utilization. For a description of the most important hydraulic systems in Italy that can be used for multiple purposes (with special reference to Sila system in Calabria and Tirso River system in Sardinia) and of the associated problems, the reader is referred to the bibliography [2].

ENEL's attention is strongly concentrated on the tools supplied by systems analysis in this field [4],[5]. The use of this technique to reach optimal solutions is indeed a must in this field where any errors in estimate may seriously affect the standards of living of the populations involved. At the moment, ENEL's main activities in this area are methodological studies and the training of experts. One of the most significant studies [6] deals with a typical small river basin used for several purposes, namely the hydraulic system of the Cellina Torrent in the Venetian Alps. The availability of basic information, the mode of utilization of its waters, and the mode of insertion into systems of a higher order permitted this basin to be taken as a model for a thorough system analysis.

In 1972, a study was started by Governmental Bodies, Research Organization, and ENEL on the planning and management of the water resources of the Tiber basin, a research program based on system analysis, sponsored and directed by the Istituto di Ricerca Sulle Acque (IRSA) of the Consiglio Nazionale delle Ricerche (CNR).

System analysis applications are also foreseen for the Tanaro and Aveto-Trebbia systems [2], aiming at the diversion of the waters from the Po basin to the Tyrrhenian coast to solve the water shortage in Liguria. For this study, a consortium has been formed by ENEL and the civil administrations of the provinces involved.

Finally, it may be worth while to point out that ENEL is setting up, for its own planning purposes, a model for simulating the operation of its electric system detailed for the hours in which the hydroelectric systems play a predominant role. In this model, Montecarlo methods are used to deal with random phenomena.

For the moment the model does not take into account the use of water for purposes other than power generation, even though provisions have been made to do so in the future. At any rate, the model will allow an evaluation of the benefits which may come from the production of electricity. This evaluation can then be used in the systems analyses of the individual basins from the standpoint of multiple utilizations of the water.

References

[1] A.M. Angelini - "Analisi degli aspetti tecnico-economici e prevedibile evoluzione della sistemazione di bacini imbriferi per finalità multipla". Relazione dell' Accademia Nazionale dei Lincei su: "Le scienze della natura di fronte agli ultimi eventi idrogeologici". Roma novembre 1967.

[2] G. Baroncini, M. Dolcetta, V. Bevilacqua - "Outlook on multipurpose exploitation of the Water Resources in Italy, and prospects under way in Southern Italy". World Energy Conference. Bucharest, 1971.

[3] E. Indri - "Quelques cas d'exploitation de reservoirs pour systemes integres en Italie". Société Hydrotechnique de France. XI Journées de l'hydraulique (Paris 1970).

[4] A.M. Angelini - "The role of systems engineering and analysis in production, transmission and distribution of electric power". Third Power Systems Computation Conference. Rome, June 1969.

[5] A.M. Angelini - "Lineamenti della Scienza ed Ingegneria dei Sistemi". da: Atti del Convegno dell'Accademia Nazionale dei Lincei sul Tema "La scienza dei Sistemi". Roma, maggio 1970.

[6] E. Indri - "Alcune considerazioni applicative sull' analisi dei sistemi idrografici ad usi multipli". Pubblicazione n. 143 (gennaio 1973) della Direzione Studi e Ricerche (ENEL).

Appendix C-Part 3:
Work upon a Mathematical Model for the Arno River

Italy

Since 1969, the Hydraulic Institute of the University of Pavia and the IBM Scientific Centre of Pisa have been cooperating in setting up a mathematical model of the river Arno. Until now we have been concerned with the study of river floods. The mathematical model should give water level and discharge values at all points of the river as a function of the rain which has fallen on its catchment area. The knowledge of these hydraulic quantities all along the river is necessary when the watercourse passes through industrial and densely populated areas, as many Italian rivers do.

We looked first at all the available data for construction of the model. For the Arno there are available many cross-sections of the main watercourse (about 1000 cross-sections for 200 km) and some rainfall and hydrometric records of past flood events. Using these data, the whole basin has been divided into a certain number of sub-basins which have catchment areas varying from 300 to 1000 km2.

In order to construct the mathematical model, we have considered two distinct aspects of flooding: rainfall-runoff transformation and flood wave propagation (flood routing). The first aspect requires determination of the discharges at the closing section of all the sub-basins as a function of the relevant rainfall. For the second aspect, we determine the variation in shape and height of the wave in its motion, taking into account the lateral inflow due to tributaries. The rainfall-runoff problem has been tackled taking into account only the surface runoff, which gives the most important contribution to the maximum discharge during a flood event.

We used a synthetic model for historical data in order to obtain, for each sub-basin considered, a function we call the Instantaneous Unit Hydrograph (I.U.H.). It acts upon the rain data to give us the corresponding values of discharge at the outlet of the basin. At present we are trying to correlate the shape of the I.U.H. with significant parameters of the corresponding sub-basin, e.g. mean river slope, mean basin steepness, area, and so on. In such a way we hope also to determine the I.U.H. for other sub-basins which lack historical data.

The flood routing problem has been solved numerically integrating the well-known partial differential equations--the De Saint Venant equations--for unsteady flow in open channels.

Only a few flood events have been used for setting up the model, (i.e. to determine the values of some parameters which characterize the friction of the river); the other data have been used to test how well the model simulates the phenomenon.

The whole model could be used also for real time control of the river or for simulating the behaviour of existing or planned hydraulic works. It could also be used, jointly with other models, for managing water resources.

All the programs are written for the IBM 360/67 of CNUCE and exploit the interactive features of the computer. In order to accomplish the work on the Arno, we must still obtain the I.U.H.'s for a stochastic model of rainfall to generate an input time series for the study of the catchment area.

Appendix D:

Comments on Papers Presented at the IFAC-IFORS Conference on Systems Approaches to Developing Countries (Algiers, Algeria, May 28-31, 1973)

Akira Nomoto

The first international IFAC-IFORS Conference on Systems Approaches to Developing Countries has been convoked on May 28 at the Palais des Nations in Club des Pains situated about 25 km west of Algiers. There were about 300 participants from all over the world including developing and developed areas.

The program included about 80 papers presented during five half days with three parallel sessions; the last day of the conference was devoted to three round table discussions. Topics discussed at the Conference cover diverse fields such as management, development policies, agriculture, food, utilities, urban planning, industry, methodology, education, human resources, and international cooperation. Though greatly differing problems were discussed, general interest focused on the applicability and efficacy of systems approaches to specific problems.

In connection with water resource problems, the following five papers should be mentioned:

1. Constraints and Strategy Choices in Water Supply Investment (I.D. Carruthers, U.K.)

2. Investment Criteria and Mathematical Modelling Techniques for Water Resources Planning in Argentina (The MIT-Argentina Project; D.C. Major, USA)

3. A Systems Approach to Assessment of Rural Water Supply Program Effectiveness (R.J. Frankel, Thailand)

4. Guideline for Systems Planning Investigations and Optimum Utilization of Water Resources and Norms in Developing Areas (D.R. Sikka, India)

5. Modelling Techniques for a System Engineering Approach of the Problems of Water Uses for Agricultural Purposes (A. Lepschy, S. Milo, D. Torriano, Italy)

Papers 1 and 3 are concerned with the rural water supply in Kenya and Thailand respectively. In the first paper, the author examines aspects of Kenyan rural water program: changes in the input mix, changes in the process for installing and maintaining schemes and the requirement for feedback. The author further describes financial and institutional background for such a development. He concludes that the concepts, if not the methods of systems analysis, would provide useful management input. In systems which are vague or relatively unexplored, systems analysis procedures can help problem diagnosis and policy formulation. Their main role should, however, be simplification rather than elaboration.

Paper 3 is concerned with the systems analysis applied to improve impact evaluation methodology by determining the role of resource constraints and complementary inputs in the development of the rural water supply program in Thailand. Methodology is developed to measure the social, economic and public health implications of water projects undertaken for rural community development. Data were taken from some 165 village projects throughout northeast Thailand. The author points out that the success of the total water system depends to a large extent on three factors:

a. general compatibility of the system's technical design with local environmental conditions;

b. adequacy of administrative procedures adopted; and

c. local operator efficiency.

He also advocated that every project in developing countries must be designed and assessed in a more comprehensive manner than has traditionally been the case.

Papers 2 and 4 discuss water resource planning. The first paper describes a case study of MIT-Argentina projects that lasted from September 1970 until September 1972. The author emphasizes two central elements of modern planning methods: multiobjective planning, and the use of mathematical programming models and hydrologic simulation models in tandem. He categorically distinguishes multiobjective planning from multipurpose planning. In the case study for the development of the Rio Colorado, nine objectives were produced. In the model studies, a series of three models was used to generate the alternative programs:

a. a mathematical programming screening model,

b. a hydrological simulation model, and

c. a mixed integer sequencing model.

In considering the use of systems technique, the organization of the program should be disregarded, especially in developing countries. Accordingly, the study structure of MIT and Argentina agency is described concretely.

Paper 4 describes generally the guidelines for the water resource planning. As a general rule, such planning is to be done in terms of the total basin with integrated plans of water resources and power development, and in a dynamical context with due linkage of technological and economic factors.

Paper 5 describes general aspects of modelling techniques and refers to the mathematical model of canal networks. The authors deem it important to classify problems into design and control. Among design problems, they distinguish between the problem of designing a single element of a system and that of designing a complex system with many interacting parts. Simulation methods for hydraulics adopted in the paper use the state variable technique, some technical cautions are given.