The process of water resources project planning: a systems approach

Project A 4.3 of the International Hydrological Programme
Report prepared by the Project Team
Editorial Board:
Y. Y. Haimes, Chairman
J. Kindler
E. J. Plate
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Unesco
Although the total amount of water on Earth is generally assumed to have remained virtually constant during recorded history, periods of flood and drought have challenged the intellect of man to have the capacity to control the water resources available to him. Currently, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a 'use and discard' philosophy -- either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management, however, should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to the solution of the world's water problems, Unesco, in 1965, began the first worldwide programme of studies of the hydrological cycle -- the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the Decade proved to be of great interest and value to Member States. By the end of that period a majority of Unesco's Member States had formed IHD National Committees to carry out the relevant national activities and to participate in regional and international co-operation within the IHD programme. The knowledge of the world's water resources as an independent professional option and facilities for the training of hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade, and, following the recommendations of Member States, Unesco, in 1975, launched a new long-term intergovernmental programme, the International Hydrological Programme (IHP), to follow the Decade.

Although the IHP is basically a scientific and educational programme, Unesco has been aware from the beginning of a need to direct its activities toward the practical solutions of the world's very real water resources problems. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the International Hydrological Programme have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multi-purpose utilization and conservation of water resources to meet the needs of economic and social development. Thus, while maintaining IHP's scientific concept, the objectives have shifted perceptibly towards a multi-disciplinary approach to the assessment, planning, and rational management of water resources. As part of Unesco's contribution to the objectives of the IHP, two publication series are issued: 'Studies and Reports in Hydrology' and 'Technical Papers in Hydrology'. In addition to these publications, and in order to expedite exchange of information, some works are issued in the form of Technical Documents.
Foreword

This volume summarizes the efforts of the Working Group for Project A.4.3.1 of Unesco's International Hydrological Programme (IHP). This Working Group was charged with evaluating the experience of countries in the application in operations research techniques in the implementation of water resource development and management.

In preparation for this study, a planning subcommittee for the IHP Working Group - Y.Y. Haimes (Chairman), J. Kindler, and E. Plate - was formed and first met in Paris during June 9-12, 1981. Sorin Dumitrescu, Director of the Division of Water Sciences, and John Gladwell, Project Officer for the Secretariat, attended this first meeting, providing important advice and insight to the subcommittee. In particular, Messrs. Dumitrescu and Gladwell posed the following questions to the subcommittee:

1. Is there a need for the project as described, or should it be modified or abandoned?

2. What would be the Working Group produce, and what would be its objectives?

3. Who would be the audience(s) to whom the products would be directed?

4. What products would be most useful (documents, training programmes, seminars, symposia, etc.)?

After an extensive deliberation, the subcommittee decided to modify the general statement of the project and summarized it in the project title -


Furthermore, the subcommittee recommended that the entire project report should be based upon case histories of the use of systems analysis in water resource project planning.

The subcommittee generated a statement of goals and objectives for the project (see the Introduction to this volume). In preparation for a workshop that was to be attended by the Working Group, the subcommittee prepared a list of thirty questions that constituted the basis for the preparation and documentation of all case studies. This questionnaire can be found in the Appendix.

The first meeting of the Working Group took place in Israel during October 25-30, 1982. Members of the Working Group in attendance were: Y.Y. Haimes (USA), J. Kindler (Poland/IIASA), E. Plate (Federal Republic of Germany), D. Rosbjerg (Denmark), I. Dima (Romania), and D. Howell (Australia). J. Gladwell represented the Unesco Secretariat. The Working Group elected Mr. Haimes as its Chairman and instructed the planning subcommittee to act as the Editorial Board. Following the meeting, U. Shamir (Israel) joined the Working Group formally as an observer.

The nominal group technique (NGT) approach was adopted by the Working Group for the preparation of the source material for this volume. The session began with brief presentations of the previously prepared case studies, referring to each of the planning stages described in the Paris report of the Planning Subcommittee. The NGT then proceeded as follows:

1. The objectives of each proposed chapter were discussed.
2. Idea generation followed, with each participant suggesting items that should be included in the chapter under discussion.

3. Brief discussion, clarification, and aggregation of the ideas followed.

4. Voting and ranking of the ideas was then done in order to reduce the number to a workable group for the next step. No ideas were discussed, however. The concept at this stage was only to select the most important ideas for later development.

5. Each participant then wrote his thoughts about each of the selected ideas. The comments were grouped by idea so that the participants had the benefit of all previous comments, and could comment on these as well.

6. The comments on each idea were typed.

The Working Group applied this technique to the first four planning stages and the introductory chapter.

The three-member Editorial Board used the results of the NGT write-ups and the documentation of the case studies (written in accordance with the questionnaire mentioned above) as the basis for the preparation of the first draft of this volume. The material was mailed to all Working Group members for review and comments.

The several members of the Working Group met during August 1983 (in conjunction with the IUGG/IAHS meeting) in Hamburg, Federal Republic of Germany, to further discuss the progress on the first draft.

In its meeting during July 6-8, 1984 in Budapest, Hungary (in conjunction with the International Federation of Automatic Control Congress), the Editorial Board generated the second draft of this volume.

Finally, in its meeting during June 24-28, 1985, in Paris, the Editorial Board incorporated the comments that the Working Group had made on the second draft and completed a final draft for the Working Group’s comments and approval.

Only case studies that were submitted to the Editorial Board in the format suggested by the questionnaire have been included in the Appendix of this volume (with the exception of Case Study 10). In order not to inadvertently alter the message intended by the authors of the case studies, no editorial work has been done on them. Therefore, the respective authors of the case studies, and not the Working Group or its Editorial Board, take credit and responsibility for the Appendix.

The Working Group expresses its gratitude for the outstanding hospitality it received in Israel during its meeting and its appreciation for the contributions of the following colleagues from Israel who participated in the Workshop: Y. Argaman, Y. Kott, M. Rebhun, J. Soroka, U. Shamir, Y. Bachmat, M. Ben Zvi, Y. Dreizin, D. Alkan, Y. Schwarz, Y. Segev and M. Waldman.

The contributions made by F. Rohde (Federal Republic of Germany) during the Workshop are also appreciated.

The Editorial Board would like to acknowledge the guidance and support provided by the IHP Secretariat through John Gladwell. Mr. Gladwell followed in great detail the progress of the Working Group and offered its Editorial Board invaluable suggestions and improvements throughout the duration of the project. We also acknowledge the efforts of the following people: Mrs. Helene Mantovani and Miss Evelyne Roumain of Unesco Headquarters in Paris for their very helpful secretarial assistance; Mrs. Virginia Benade of Case Western Reserve University, Cleveland, Ohio,
for her careful and constructive editorial work; and Mrs. Mary Ann Pelot of Case Western Reserve for her dedication and secretarial assistance throughout the entire project.

This volume is addressed to water resource planners and decision-makers in both developing and developed countries. It is intended to be understood without major prior knowledge of water resources terminology, and it can be used as an aid for undergraduate courses on water resources planning (following an introductory course on systems analysis). The following is a complete list of all members of the Working Group:

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Introduction

The international literature on water resources planning includes many applications of systems analysis and operations research techniques to water resources projects. Excellent textbooks exist on various aspects (for example, Wiener 1972; Haines 1977; Goodman 1984; Cohon 1978; Loucks et al. 1981), and numerous problem methods are available for finding optimum solutions or good compromises (Goicocchea et al. 1982; Haines et al. 1975).

The need to find optimum solutions in water resources is compelling indeed. The more we look into the development prospects of any of the countries of the world, the more we perceive that future growth is almost everywhere severely constrained by the shortage of water of sufficient quantity and quality, a shortage which only in rare cases can be overcome by making new resources available. In general, we must make better use of the available water, and we must employ better methods for conservation, distribution, and purification. The severity of these problems has been recognized, and international and national programmes have helped to disseminate information on water problems and to draw the attention of public and political bodies - such as the Mar del Plata Water Conference of the UN in 1977 and the International Drinking Water Supply and Sanitation Decade Programme - to such problems. Scientific support programmes proliferate, such as SCOPE, HOMS, and the Unesco International Hydrological Programme. In all of these, optimization or systems analysis techniques are widely recommended.

It therefore is strange to find that, in comparison with the extensive literature on the methods of systems analysis, there have been few reports of the successful implementation of such methods. It seems that a gap exists between the state-of-the-art of systems analysis techniques and their current use in practice. A recent report by Loucks et al. (1984) has indicated that only a small part of the studies of water resources systems which were reported in the literature were actually used by the decision-makers for whom they were intended. Since the published literature is only a vague indicator of what is going on in the practicing real world, a working group within the International Hydrological Programme was established and it was assigned the task of finding out what has been the experience of the member countries that use systems analysis techniques. This group, called the Working Group on IHP Problem A.4.3.1, was initiated by a meeting of the planning subcommittee.

The Working Group's planning subcommittee, at its first meeting in Paris in 1981, reviewed the situation and arrived at the conclusion that it would not be sufficient to view the success or failure of systems analysis in the overall context of water resources management and planning: the group should also identify the levels and stages of the planning process and perceive the application of methods as specific to them. Only in this way could the present place of systems analysis in the planning process be recognized and a differentiated statement concerning the acceptance of systems analysis techniques be developed. In particular, the planning subcommittee adopted the notion that the water resources planning process addresses, and must be responsive
to, many aspects of water resources planning (e.g., hydrological, scientific, technological, institutional, and decision-making). Having accepted this idea, the group agreed that its effort should offer a framework that would enable the quantitative aspects of water resources planning to be integrated with the more subjective/value judgment and qualitative aspects of the decision-making process—a process influenced by political-institutional trade-offs with dynamic and drifting objectives. The planning subcommittee also agreed on the following objectives of this project:

1. Provide a systems framework for the planning process in water resources development.

2. Cast operations research/systems engineering into the context of a real-world water resources planning environment.

3. Provide instructional material that can be used to teach water resources planning.

To illustrate the breadth of the water resources planning process, the following representative premises were identified to serve as guidance to the Working Group.

1. Water resources systems most often have multiple objectives, use, and functions.

2. The consideration of the scientific and technological aspects of water resources problems is a necessary condition for a successful planning process, but not sufficient; institutional and other considerations are essential.

3. Multiple decision-makers, who represent various constituencies, needs, and aspirations, are commonly involved in the planning process and thus should be properly accounted for in the process.

4. Elements of risk and uncertainty characterize most, if not all, water resources systems.

5. The planning process is hierarchical in nature, as is the decision-making process.

6. The components of problem definition and formulation, data collection, and modeling constitute a more dominant effort in the planning process than the optimization per se.

7. The process of water resources planning involves experts from many different disciplines, such as hydrology, engineering, economics, political and social science.

Based on these concepts, the planning subcommittee designed a general scheme of the planning process, identifying six stages ranging from project initiation to management of the complete project. They devised a set of thirty questions on these stages, and this questionnaire was sent to all members of the Working Group with a request to present case studies from their countries by answering the questionnaire.

The results of these activities are found in this book. Its purpose is to discuss and explain the planning process with emphasis on the use of systems analysis, and to illustrate this process by means of different examples taken from the experiences of water resources engineers and scientists from many different countries. In general, we perceive the planning process as a sequence of decisions at many different levels and by many different groups of experts and concerned persons whose objective is to provide a solution or solutions to large-scale problems, in our case involving the utilization of water resources. This process can be subdivided into different but interrelated stages, each with its own characteristics and subproblems, by means of a model of the planning process, which provides a general framework for the case studies. This general framework is described
in the first five chapters; the sixth chapter provides the introduction to the case studies, which are appended to the book.

In our description of the planning process, we use terminologies and terms that are understandable to engineers and planners, and the discussion is in general terms, leaving analytical details to the case studies or to the literature to which reference is made as appropriate. It is not the purpose to point out analytical solutions; indeed, the case studies illustrate why analytical solutions may often not be needed. Naturally we recommend that systems analysis techniques and operations research be used whenever applicable, but we realize that an optimum real-world solution does not necessarily consist of a solution which is, mathematically speaking, the true optimum. The real-world optimum is usually the compromise solution on which all parties involved in the planning process can agree, and we emphasize in this book the analytical aspects of this process.

The planning process as here described not only encompasses the stages that lead to the design of structures in a new project; it can also be applied to existing systems on which new demands are made, or to projects which have little to do with structures, such as general water plans or regional development plans. The planning process includes many aspects of operation and maintenance, although these stages of the planning process are not detailed here. The book is not concerned with the construction and management stages that are part of any project involving structures and equipment in its implementation. It is hoped that this book will convey to the readers a sense that the systems approach can provide one with a method by means of which water resources planning can be structured and made amenable to analysis.

This book has the following objectives:

1. Document and evaluate the applicability of systems analysis used in the various stages of the water resources planning process.
2. Contribute to the development of a common approach for project planning in water resources.
3. Articulate problems that may defer application of systems analysis and plan acceptance; and, perhaps, provide the means of overcoming them.
4. Serve as a textbook for Unesco courses on water resources planning.

The questionnaire that was prepared for each of the planning stages and that was used as a guideline for the case studies is presented as Appendix 1.

References


1. The systems approach in water resources project planning

The process of bringing a project into existence can be thought of as consisting of three phases:

Phase 1. Planning

Stage 1. Plan initiation and preliminary planning
Stage 2. Data collection and processing
Stage 3. Formulation of and screening and project alternatives
Stage 4. Development of final project specification
Stage 5. Project design

Phase 2. Implementation

Phase 3. Project Operation

The overall process is shown schematically in Figure 1.1. The scope of this book is limited to Phase 1, focusing on the planning of regional water projects that are initiated in response to the specific economic and social needs of a region or nation. These projects may be of a structural or nonstructural character; they may be of a single- or multiple-purpose nature; however, their analysis must always be multiobjective in character. This is because evaluation of project alternatives must always be carried out within the broad spectrum of objectives, and various project impacts must be taken into account. Phase 1, the planning process, consists of a number of stages. Each of these stages has a definite function and is separated more or less distinctly in time from other stages. Although only the planning phase and its five stages are considered in this book, the planning process needs to take cognizance of Phase 2 and Phase 3 and use their ingredients for project planning purposes. These last two phases, of course, depend on the first, and they can also lead to future projects.

The planning process is described in this chapter as consisting of stages related to different levels of decision-making. We begin with introductory remarks on the nature of water resources systems and their planning and then present a general framework for the planning process. The concept of the planning process is summarized in Figure 1.1, which provides the structure for the remaining chapters of the book.

1.1 Characteristics of water resources project and project planning

A water resources project is a set of structural or nonstructural activities for the purpose of developing or improving existing water resources for the benefit of human use. The ultimate goal of water resources planning and management is to serve the public well-being - to ensure that water will be available, in sufficient quantity and quality, at the right location, and at the right time, and to protect human activities from the harmful effects of water; all this must be done within accepted levels of assurance.

Water resources planning is a logical course of actions leading to the selection of the best acceptable project in response to an identified need. Because of the wide regional distribution of surface water and groundwater resources, water resources planning is always very broad in scope. Such planning requires that many different uses of water be considered and evaluated, leading to the articulation of trade-offs among conflicting and competing objectives. It requires that decisions be made on many different levels, ranging from national or even international water plans to regional or local projects and involving experts and decision-makers who have different
backgrounds and who are often not water-cognizant: politicians, lawyers, and social scientists. The objectives that such a varied group consider important for a particular water project many differ very widely. Water resources planning therefore requires a planning team that is well coordinated and in agreement on the objectives and scope of the project, who can present a final project plan that represents the agreement of all team members. This is not an easy task, because water resources are subject to natural variations, and future changes in demography and economy are difficult to predict. This is a major way that elements of uncertainty enter the process; these elements are essential, and in many cases dominant, features of water projects. Other complications specific to water resources projects are due to the fact that many water resources decisions are irreversible. For instance, a dam that has been built in a river valley exists practically forever, regardless of whether there is a need for it or not; it will never be possible to restore the site to its original condition, even if society is willing to provide funds for the removal of a dam that is no longer needed.

Because of the complexity of the issues involved in water resources planning and because of the large consequences that result from decisions on water projects, planning methods must be employed which can handle such problems. This is how the systems approach enters the analysis of water projects.

1.2 Water resources systems and models

A physical water resources system is a collection of various elements - for example, reservoirs, pipelines, and other structures - which interact in a logical manner and are designed in response to various social needs. Water resources systems analysis is an approach by which the components of a system and their interactions are described by means of mathematical or logical functions. In general, systems analysis is the study of all the interactions of the components. Very often systems analysis is concerned with finding that combination of components which generates an optimum, i.e., a system which consists of the best possible combination of elements for satisfying the desired objective. This statement should not be interpreted as requiring that the use of system models must lead to an optimum solution in the mathematical sense, in which an objective function is minimized or maximized. Unfortunately, in water resources systems, more emphasis and effort have been focussed on optimization techniques than on more realistic mathematical models.

There are two reasons for the overemphasis on optimization techniques:

a) Abundant optimization techniques are available in fields other than water resources engineering, such as operations research, systems engineering, and control theory.

b) The mastery of optimization techniques requires far less experience, effort, and professional maturity than the mastery of systems modeling. Consequently, it has been quite common to apply optimization techniques to poorly constructed models, which often represent a distortion of the real physical system and are thus misleading if not erroneous.

There is a present trend toward achieving a better balance between systems modeling and its associated optimization techniques.

If systems analysis methods are to be employed in the study of a water resources system, the latter must satisfy a number of conditions. First of all, it must be possible to identify the combination of objects which form the system and to separate them logically and functionally from all other elements of the planning region. Thus, a bridge is to be seen as an object which impedes (or does not impede)
river flows - if it does, it becomes part of the system of conveyance channels over which it leads; if not, it can be left out. Second, we must be able to identify the elements and be able to describe their functions, i.e., to develop a process model for each component, and we must be able to quantify their relations with the other elements of the system. Third, one has to be able to combine and/or coordinate component models and to define objective functions in such a way that the objectives to be optimized can be expressed in terms of the systems variables.

Systems analysis may be used to find a 'best acceptable' solution. But this is not its only purpose. Often it is applied for "structuring" a water resources project. By structuring it is meant that the systems elements are drawn into a block diagram and connected by means of logical statements. When a system is represented in the form of such a diagram, it is easier to "see" how different components must interact for the system to perform properly, or how the system interacts with its environment. By isolating subsystems of the water resources system, their performance can be tested and analyzed separately. In this manner, the systems approach gives transparency to the planning process and simplifies the discussion on all levels of the decision-making process; and it easily permits addition or deletion of different components or interactions.

The systems approach is especially useful when a project becomes so large that it cannot be considered as a unit, necessitating its decomposition (disaggregation). In contemporary projects, systems are so large or complex that they can only be analyzed with the aid of computers. These are needed because of the complexity of the relationships - for example, dynamic systems that have nonlinear interactions - or because of the multitude of purposes or possible combinations of systems elements, or because of the need to incorporate stochastic variability into the system analysis. Within the framework of computer-aided systems analysis, the planner has to recognize the existence of

(i) multiple constituencies
(ii) multiple decision-makers at many levels of the hierarchical structure
(iii) multiple objectives that are noncommensurable and are often in conflict and/or competition
(iv) multiple purposes and/or uses of the water resources system
(v) elements of risk and uncertainties

These characteristics dictate that the planning team be composed of experts who represent the multidisciplinary/interdisciplinary nature of the issues being considered.

However, systems analysis is not an approach that can be used automatically and without thinking. Usually, the greatest effort of the analyst is to reduce the system to a manageable representation without destroying its essential features and relationships. The analyst may overlook important relationships because he may lack access to all necessary data, and usually time is not sufficient in an actual planning environment to develop the ideal model and test it to its fullest extent or to subject it to the scrutiny of several experts.

Typical models include process models, i.e., mathematical models which describe the physical and other processes symbolized by system elements: input-output models of water quantity and water quality parameters for rivers, reservoirs, groundwater, and distribution systems, such as pipe-lines and canals. Process models can be considered as representing purely static relations, such as the river stage-discharge relationship, or
they can represent dynamic processes such as the outflow from a reservoir, or the motion of a flood wave in the river channel. These models in their usual form are of the deterministic kind, but within the framework of systems analysis it might be necessary to consider stochastic or non-deterministic aspects, such as those due to the time variability of the runoff process or the random nature of the runoff coefficients. The process models are often part of conventional design procedures and therefore are familiar to planning engineers. But systems analysis, in addition, employs other types of models, such as decision models. Optimization models, such as linear programming, dynamic programming, or the surrogate worth trade-off method, are important tools and procedures for solving decision problems by optimization. Other decision models may not use optimization techniques, such as many simulation models.

The driving force in the optimization models is the objective function (or functions in multiobjective optimization), and any "optimal" solution derived is clearly dependent on the assumptions and criteria and their associated uncertainties. Some of these uncertainties might be derived from the selection of model topology (structure), parameters (coefficients), scope, or focus. Others might be related to data, the optimization techniques used to solve the mathematical models, modular subjectivity, or the inability to account in the model for many of the nonquantitative and nontangible considerations. These factors and others, such as the sensitivity of the models and their stability, have somehow caused skepticism about optimization models and systems analysis in general among the practitioners of water resources planning and management.

The term optimal solution essentially refers to the best solution of the mathematical model under all assumptions and constraints, whether explicitly stated or implicitly included in the formulation. Clearly, then, the optimal solution indicated by the model may be far from, or even have nothing to do with, the actual system's optimal solution.

Recognizing all these difficulties, mathematical models have significantly expanded the ability to understand, plan, and manage our water resources. Models are currently used to investigate virtually every type of water resource problem, for small- and large-scale studies and projects, and at all levels of decision-making. In some cases, models have increased the accuracy of estimates of future events to a level far beyond "best judgement" decisions. In other cases, they have made possible analyses that could not be performed empirically or without computer assistance. Further, models have made it feasible to quantitatively compare the likely effects of alternative resource decisions.

Models are usually very useful for analyzing complex water resource problems. While many of the economic and social factors in water resources planning cannot be fully enumerated, models can be used to integrate the available data and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different alternative plans, and using them is often less expensive than conducting comprehensive surveys or using other traditional approaches.

A prerequisite for a systems analysis is that all the elements of the system can be modeled either analytically or conceptually. It is important to distinguish between system and model. A model is the mathematical and/or physical representation of the system and of the relations between the elements of the system. It is an abstraction of the real world, and, in any particular application, the quality of the model and thus of systems
analysis depends on how well the model builder perceives the actual relationships and how well he is able to describe their functional form.

Since models are abstractions of reality, they do not usually describe all features that are encompassed by a real-world situation. A prerequisite for the systems analysis of a water resources system is the description of the system in terms of component models which permit solutions to be obtained at reasonable cost and within a prescribed time frame. Therefore, the model builder should not attempt to model the reality of individual components as closely as possible, but only as closely as is necessary to meet the overall accuracy requirements for his system. To illustrate: if the objective is the design of a large storage reservoir for irrigation and water supply, it is quite unnecessary to model the complete runoff process. On the other hand, a model well-suited for a storage reservoir, such as a monthly flow-generation model, is entirely unsuited for modeling the peak discharges. When, for example, should the engineer who designs a sanitary sewer system for a city employ a model of nonstationary flow routing (such as the complete St. Venant equations), and when is it sufficient to design for stationary flows, for example, by just employing the concept of normal depth and Manning's equation? The difference in computer time for the two methods is very large, and the stated question is a valid one. Hence, it seems that an important aspect of model building in the context of systems analysis is to find the best but permissible simplifications. Other reasons for searching for a simple model may be imposed by a lack or low quality of data. For example, a nonlinear unit hydrograph model is usually not useful because the variability of the runoff coefficient together with the lack of sufficient parallel measurements of rainfall and runoff events make it impossible to get calibrations that are accurate enough to make the nonlinearity perceptible in a statistical sense.

In a recent study commissioned by the Office of Technology Assessment of the Congress of the United States (U.S. OTA 1982), a group of leading experts assessed the capability of surface-water flow and supply models, surface-water models, and groundwater models, the latter including both quality and quantity aspects. They were rated according to two criteria: reliability of the model and credibility of the model results. Models are considered reliable if they accurately describe the physical or chemical process for which they are designed. Credible results require both a reliable model and sufficient data to run it. Tables 1.1, 1.2, and 1.3 (which are copies from Tables 2, 3, and 4 of the OTA report) show the assessment for the three types of models. The evaluation key is listed at the bottom of the table. It is seen from Table 1.1 that the experts consider surface-water models to be generally adequate, although considerable improvement is possible to raise most of the models from a C ranking into the A class. Roughly the same state of affairs is listed for the surface-water quality models and for groundwater models, but it must be realized that the rating by credibility and reliability alone, without due consideration of economy and position in the conceptual frame of the water resources systems, may not be sufficient for assessing the models' value for systems analysis.

1.3 Levels of decision-making

Many water resource projects are very large, and large sums of money, very often public, are involved. They are competing with other needs for society, and they influence many other sectors of the structure of society. Therefore, the decision process which leads to the implementation of a water resources project take a long time and decisions are made on levels which are political and
socioeconomic rather than technical.

The basis for a decision on a water resources project is a plan in which the objectives of the project are outlined as well as the means by which they are to be accomplished, their costs, and the consequences of the project in terms of benefits and adverse impacts. Water resources planning is the sum of all activities which lead to such a plan. The larger the project and the more intensive the use of the water resources, the broader becomes the scope of the planning process. There are few water resources projects which have only local consequences, and most of them have to be seen in the broader context of regional or even national or international development. It is therefore tempting to evolve a hierarchy of levels for water resources planning, with the hierarchy beginning at a level where all possible projects are considered in the context of a general economic master plan for a country. Of course, a plan which comprises all political, economic, and sociological development objectives in detail is neither useful nor manageable. Therefore, a national water plan must generate subplans, which cover more details for a narrower area.

Typical of such a hierarchy of planning is a division into three levels. In the U.S., for example, the following levels are promulgated by the U.S. Water Resources Council (1973).

(i) Level A, a reconnaissance study or a general framework study. The temporal horizon is about 30 to 50 years. The major purpose is to identify major problems or prospective problems. The area is generally very large.

(ii) Level B is a comprehensive planning effort for a smaller region. This level should follow Level A, where problems have already been identified. The time horizon is about 15 years.

(iii) Level C is implementation planning, where specific project designs are developed. Generally, Level C should follow Level B, because specific plans or recommendations from the Level-B effort are implemented here.

Other countries use different terminologies to describe the planning levels, but in general one can identify three levels, and these are often associated with different planning authorities. The first level involves international agreements of water use, for example, the allocation of water from a river which flows through two or more countries. At this level, national water plans are adjusted to international demands. These agreements are hardly ever reached on the basis of water resources development alone, but involve many different national interests.

The second is the national level. The purpose of water resources planning on this level is to set priorities for the long-term development of a country. An example is the National Water Plan of Hungary (David et al. 1977). Its decision level is largely political and involves technical inputs only on a limited scale, usually only as financial data or constraints. Although decisions on a national or international level are of great consequence since they set the strategy for development, in this book they are not given much room. At these levels it is often decided whether to proceed with the planning for a project, and whether to make funds (direct financing or matching funds) available for it. The procedures for planning on the national level differ for different countries, and some details are given in the introductory section of each of the appended case studies.

The third level is regional, its results being incorporated into a regional water plan which identifies water resources projects within the context of the different requirements imposed by alternate
development plans of a region. The Maumee River study in the USA (Case Study 4) or the Marchfeld case in Austria (Nachtnebel et al. 1982) are examples of such broad-scale regional water plans. The objective of such a study is to set priorities and to make recommendations for the allocation of different water resources to different water users.

1.4 Stages in water resources planning

The systems definitions of the previous section are applicable to different types of planning processes and they are not specific to water resources systems. This lies in the nature of the systems approach, and in classifying water resources systems we have to recognize both the general aspects of all systems and the specific aspects of water resources. Most typical of the latter is the use of classification by purpose. The purpose of a water resources system may be water supply, irrigation, flood control, hydropower generation, or navigation; or some or all of these purposes may be combined in multipurpose projects. In the systems framework, this classification is not very useful because the systems models for these purposes are very similar in their formal aspects. The major differences lie in constraints (which arise from restrictions on individual purposes), in objective functions (with different societal and economic goals to be achieved for different purposes), and in the design aspects.

A second classification is by stages of the time sequence of the planning process. The scope of the planning process in water resources can vary from the very broad-based preliminary planning of a water resources project, which follows the partial identification of a need for action, to the more detailed evaluation of a selected physical project (a "feasibility" study). The project may be financed or supported by private parties, or it may be part of a large-scale, internationally financed activity, although in this book emphasis is on planning efforts at a national or regional scale. Thus, when we set up a classification by stages of the planning process it must be broad and flexible enough to incorporate all these properties of water resources projects and to permit analysis by any suitable systems analysis technique. A classification which makes this possible is presented in this book and is depicted in Figure 1.1. It identifies the following stages of the planning process:

Stage 1: The project initiation stage, which begins with the statement of needs and includes preliminary planning that ends with the decision on how to proceed.

Stage 2: The data collection stage, in which data are gathered for system model development and decision-making.

Stage 3: The process of determining the final project configuration, in which all alternatives are investigated and a small number of representative and promising alternatives are selected for detailed analysis.

Stage 4: The process of planning in detail. In this stage, the design parameters, operation rules, cost, benefits, etc., of the alternatives selected in Stage 3 are determined, and the final project configuration is selected. This phase repeats, in more spatial and temporal detail, the planning of Stages 2 and 3, and often is performed by a different team of planners.

Stage 5: The design stage, in which the final configuration is translated into design documents.
Note that Stage 5 is not a direct part of the water resources planning process, since it mostly involves structural and other details, if a project is of structural nature. In many projects which are nonstructural, this stage does not exist, for example, if the changes of functions for an existing project are analyzed. We therefore shall not discuss Stage 5 in this book.

This classification into five stages is only one of many similar classifications and is not the only one which is in general use. For example in international project planning activities such as the ones used by the World Bank or other project planning and financing agencies for developing countries, a grouping by stages is used which essentially combines Stages 2 and 3 into a prefeasibility study, which forms the basis for funding decisions, and which also combines some aspects of Stages 2 and 4 into a feasibility study that provides the basis for the final financial decisions that are made before the project is designed and executed. However, most national projects subdivide themselves into five stages in a natural manner, since each stage involves decision-makers and analysts.

The stages of the planning process encompass planning at each of the levels described in section 1.5. But, whereas the levels refer mostly to the decision-making agencies, the stages are seen more from the logic of systems analysis. There exist, therefore, important differences. However, levels and stages form a network of the decision process, and they interact and are strongly interdependent. This requires a structured administration in which, at all levels and stages, authorities (and responsibilities) are assigned, procedures of information exchange and of legal actions are established, and procedures of interacting with the users of a water resources project are developed. Different countries have generated administrative procedures of different kinds, as is exemplified in the case studies. Other examples are given for various countries by Jamieson (1979), by Williams (1984) for the United Kingdom, and by Shamir (1983) for Israel.

In terms of water resources planning and operation, a country may be considered developed if it has an administrative structure which guarantees careful operation and maintenance of completed systems and which has sufficient flexibility to adjust to changing needs. Indeed, a good case can be made for assigning a high priority to the establishment of a well-functioning water administration with strong powers of regulation and a well-trained maintenance staff, giving it a much higher priority than the production of a large-scale project. Countries that have an already-developed water resources administration that could evolve with the advent of large-scale water projects have certainly been in a more fortunate position. They have been more aware of the consequences and limitations of water resources projects than countries with little or no administrative structure which suddenly have been confronted with the task of administering a huge water project fashioned through the will of well-meaning politicians, the finances of an international funding agency, the planning of an international consultant firm, and the construction crews of a multinational contractor!

A well-designed plan for a water resources project should require the execution of each of the stages, allowing enough time and resources in funding and manpower to provide a solid base for decision. Unfortunately, such a careful study of a project is usually not possible, sometimes because of limited funds but more often due to time limitations. Partly this is caused by the lack of data: e.g., long records of runoff data that are based on a statistically significant number of years of runoff
measurement are often not available, and measurement of lacking data can only start during or at best shortly before planning. In earlier times, the planning and construction of a large water project took decades, during which time additional data could be gathered. But today, particularly in developing countries, the data base does not exist, and the time horizon is so short that the planner finishes his job only just before the contractor takes over. Even if the planner can continue the data-gathering phase during construction, methods are so efficient that the project is completed in a few years instead of decades. Population pressure or national development plans also may impose time constraints. The net result is that Stage 2 often is done only on a limited scale, and is done as part of Stages 3 and 4.

Other cases exist which may make Stage 4 unnecessary because the one solution of the water resources project is obvious or, as is the case in many densely populated countries (for example, in Western Europe), there exist many types of projects which are so narrowly constrained by different interests that a particular option is the only feasible one.

1.5 The planning process

The definition of the five stages of planning yields a conceptual model of the planning process, which is shown in Figure 1.1. Here, the stages are shown as part of a sequential decision process, in which the tasks to be executed in each stage are represented by boxes and the connecting lines denote decisions to be taken, or the information flow which is passed on, from one stage to the next. The direction of the information flow is indicated by arrows. However, the connecting lines are only schematic, and additional feedback loops may exist. The other stages, such as construction and operation, are not part of the planning process as defined here. In fact, it must be understood clearly that the operation rule resulting from the planning process is a first approximation only; experience with the actual project will have to be incorporated into improved rules. The planner must allow enough flexibility for later adjustments, because most operation rules are developed on the basis of some kind of a forecast, and it is very unlikely that the real world will behave as predicted during the planning.

Figure 1.1 applies to all levels of planning, perhaps with some of the stages combined or omitted. It does not give information on how the stages are to be executed or what methods are to be used. In most countries or organizations, the planning regulations or rules given to water resources planning boards are spelled out in more detail. As an example, in the FRG the planning process is described for the national and regional levels by public laws which mostly are intended to set procedures for the process of approving projects, while the stages of project planning for some types of projects are outlined in standards (for example, the reservoir planning process is spelled out in standard Nos. DIN 19700-10, in which a procedure is described which roughly corresponds to the stages of our Figure 1.1). These laws and regulations are not expressions of national objectives, but other countries have included such national objectives. For example, the Principles and Standards of the Water Resources Council of the U.S. are rather explicit in the priorities that are to be used in the planning process. The planner must realize that objective functions may shift due to the shifts in value judgments or development objectives, and this is part of the uncertainties (called the "strategic uncertainties" by Kisiel and Duckstein (1972)) which he has to allow for.

It will be the purpose of the following chapters to describe the
stages of the planning process in more detail and to interpret the boxes of Figure 1.1. The general procedure for the planning of a project usually begins with the designing of a diagram of the physical system, consisting of geographical maps showing the locations of demand and supply as well as the locations of typical structures and their connections. Such a map (as is appended in more or less simplified form to each of the case studies) forms the basis for a system diagram - a block diagram of the system. This block diagram represents the system in its state of operation. The process described in Figure 1.1 is then the process of modifying and quantifying the initially conceived system (of Stage 1) through Stages 2 to 5 to its final design.

It is useful to consider Figure 1.1 as a guide by which to approach the planning process. However, the procedure does not guarantee the quality of the results of the planning; this depends on the correctness of the system elements and of the data describing the system. It is necessary to obtain all the needed information on each of the system elements before any system analysis is to be performed. For this, checklists are sometimes used.

However, even the best checklists and planning schedules can only be a guide, and they must be used with care and discrimination. They can supplement, but not replace, the skill and intuition of the experienced and creative planner. He must decide on the variables and the values of constants and parameters, he identifies and decides on the importance of constraints, he determines the most appropriate state transition function of logical or structural elements. And, finally, no hard-and-fast rules exist on what planning procedures are to be used; the finding of the best approach for addressing the planning process is a difficult problem in itself.

1.6 Advantages and (current) disadvantages of the systems approach to water resources

Analysis of water resources systems and water resources planning for such analysis are very old activities - in fact, the vast irrigation projects of Mesopotamia or Egypt or China, built well before the beginning of our times, were certainly done with careful planning, based on long observations and experience. Such systems were subject to improvement over centuries by trial and error, linking the society of the country and its administrations to the management of water and the utilization of the water resources. And thus it has been through the ages. But, in spite of the important role which water resources development played in the development of some countries, it has only been through the efforts in other areas of planning that the analytical background for modern systems analysis has been created (Rogers 1980). Therefore, modern systems analysis techniques have entered the planning of water resources systems during the sixties (Maass et al. 1962; Hall and Dracup 1969; Buras 1972).

Systems analysis proponents have established the science of water resources systems analysis with an enthusiasm which is unsurpassed by any other areas of water research, so that today a vast expertise exists to optimize real (and imagined) water resources systems. The reason for this enthusiasm is easily understood, because systems analysis techniques opened up the murky field of decision-making in water resources engineering, handled up to then only by intuition and experience (so it seemed), to the clarity that mathematics gives to analysis processes, and so to the introduction of objectivity into what seemed to be subjective and in some cases arbitrary decision processes. A breakthrough was made possible by the computer and its capability to work with large
amounts of data and to solve complex mathematical problems. With this capability, the systems formulation was quantifiable, and the advantages of systems analysis could be realized to the full extent. As time passes, the systems approach will assert itself. New generations of computers, including minicomputers, become available to the engineer to increase his planning capability on his desk, and to increase the efficiency of operation through adaptive controls, forecasting techniques, and adaptive accounting for all factors influencing the system operation.

The systems approach becomes a necessary planning instrument because it seems to be the only way to integrate the many issues which the water resources planner must consider in his plan. Environmental protection, the issues of water quality for human well-being, requirements of recreational use, the issues of conflicting demands on scarce water resources - for all of these problem areas, solutions have to be found which must be able to withstand the scrutiny of professional experts and of an increasingly well-informed and critical public. Many of these people have seen the failures of conventionally planned projects in which a single purpose was followed without regard to impacts on other areas. Examples of detrimental impacts are reservoir and river-bed sedimentation, abuse of water in irrigated areas generated by the apparently abundant supply of water from irrigation works, and water pollution by industry and cities. These are only a few examples of the negative consequences of a sectorially oriented and noncomprehensive approach to water resources planning. On technical grounds, the main advantages of the systems approach in water resources planning are:

1. Objectives can be stated quantitatively, often in analytical terms, and objective functions and constraints can be formulated, permitting generation of a plan that accounts for all the sectors which influence or are influenced by a water resources project.

2. The level of performance of a system, as measured against certain performance standards, can be quantified, allowing the incorporation of risk and uncertainty into the decision process.

3. It becomes feasible to make complex models of real-world water resources systems so that a much lower degree of abstraction and simplification is necessary than in conventional approaches. This is an advantage which is a necessary prerequisite for addressing issues, in particular those of a multiobjective and multipurpose nature.

The very advantage of being able to handle large and complicated planning projects is also the main disadvantage of the systems approach. First of all, there is the problem of the quality and quantity of data which may be required, with all the limitations set by funding and time for data acquisition. This problem is discussed in Chapter 3. Then there is the problem that the decision-maker may find himself confronted with a selection of decisions that are not obvious to him and which have been obtained by analytical procedures that he cannot understand without investing substantial effort, for which he usually has no time. And systems analysts, many of them intoxicated by their computers, are not helpful; communication in plain language, or in the language of the engineers, seems to be more difficult than solving complex mathematical problems. The decision-maker views the results with suspicion, or worse, with a false confidence that may not be justified because of planning errors (which happens!) or the use of models which have not been developed far enough to permit the conclusions for which they are used.
At this stage it seems worthwhile to list some of the more commonly perceived shortcomings of systems analysis as applied to water resources planning; we can then analyze trends in the development of systems analysis aimed at overcoming these difficulties. Following are the major sources of the skepticism that many agencies have about the possibility of actually implementing systems methodologies in water resources planning and management:

(i) Single-vs. multiple-objective models. Single-objective-function models have dominated most past studies in water resources planning. Yet the many competing and often conflicting goals and objectives of almost every water resources system make such models incompatible with reality and therefore unacceptable. A water resources agency may not find models with a single-objective function to be acceptable as a decision-making tool if, for example, the problem it attempts to model is characterized by multiple noncommensurable objectives and goals. Future water resources planning models are likely to encompass multiple-objective functions in their noncommensurable units.

(ii) "Soft" vs. "hard" elements in modeling. There is a growing need to include in the modeling considerations the so-called "soft" elements - such as society, politics, legal aspects, and the environment - along with the "hard" elements such as economics and the physical-technological system. Consequently, new approaches and methodologies capable of coping with these complex "hard" and "soft" elements and bridging the gap between them are being developed. These new approaches are based on various theories and concepts, such as decision theory, game theory, utility theory, fuzzy set theory, vector optimization, and simulation with interactive modes.

(iii) "Narrow" vs. "total" models. A basic concept being preached to students of systems analysis is that, for the analysis of a system to be meaningful, the whole system should be considered. Yet, most well-documented simulation and mathematical models of water systems are aimed at investigating narrow, specific, and selected aspects of a regional water resources system. By virtue of tackling one part of the problem while assuming knowledge of other parts, these models are often one-sided and usually do not represent the overall system behavior. The reason they are oversimplified can be explained by the difficulty of solving the problem of using conventional systems analysis tools to model a large-scale, complex system. The future trend is toward modifying existing models to incorporate them into the analysis of the total system. This can be done by using hierarchical-multilevel structures that relate and coordinate the various submodels and objectives of the total system.

(iv) Lack of data planning. In many countries there has been a lack of interaction between data-collection agencies and those in charge of water resources planning and management. There is an acute need for analytical frameworks capable of evaluating the worth of data for an optimal data-collection system (with respect to collecting, processing, disseminating, and projecting future data demands). In addition, these operational frameworks ought
to be responsive to the needs of planners for management of water and related land systems.

(v) Lack of interaction with the decision-makers. Water resource systems analyses have often been done in isolation from the decision-makers and commissioned agencies responsible for, and in charge of, implementing the results of these analyses. Trends indicate that more emphasis is being placed on constructing more-realistic models that are acceptable to these decision-makers and agencies. Closer communication and cooperation between systems analysts and national and local agencies should be established.

(vi) Lack of follow-up in implementation. The majority of studies of water resources systems are conducted by one group or agency and implemented, if at all, by another. This lack of continuity and follow-up of the study by the modelers and systems analysts often results in misunderstandings of the models by the implementing agencies. Most importantly, the experience and know-how gained by modelers and systems analysts are not utilized where they are badly needed. Again, the trend is in the direction of more communication between the two groups so that a closed-loop operation replaces the present open-loop one.

In systems analysis, it is not the model in itself that counts, but its performance. As was pointed out above, to cast a real-world problem into the framework most suited for a certain type of analysis very often involves the simplification of the problem in certain areas. Are the simplifications permissible? This is an important question, but not nearly as important as the question of whether all significant variables are accounted for, and whether the numerical values of the parameters and coefficients which are used are of the right magnitude. Since the systems analyst usually does not have the broad experience required for such insights and the experienced engineer (planner) does not know enough about planning techniques, it is a prerequisite for a successful planning effort that decision-makers, systems analysts, and engineers (planners) work together in an atmosphere of mutual trust and willingness to learn.

In such an atmosphere, the advantages of systems analysis greatly outweigh its disadvantages, and by leaving the problems which cannot be resolved by presently available techniques outside of the system model and evaluating its aspects separately by conventional methods, the systems analyst can substantially improve the planning process without inspiring a confidence that is not justified.

It is difficult to speculate how systems analysis in water resources will develop in the future. The systems approach is used to solve the old problems of water resources, but on a higher level than the "old" techniques. We must assume that there are higher levels still to be found - but we do not know of them, just as the planners of yesterday did not know. But we venture to predict that the foreseeable development will be in the direction of closing the communications gap and making the planning process more transparent. Mathematical system models will evolve into a support framework for decision-making that includes numerous smaller models that are self-contained and designed to be used interactively by analysts and policy-makers at different levels. Better physical models, better economic models will be developed. Minicomputers and interactive software will be used to make decisions more transparent and help decisions to be accomplished in sessions of experts who are
the common language required by systems analysis.

There will also be developments at the higher levels of planning, dictated by needs of ever-increasing complexities of economic and social institutions for which water resources projects provide part of the infrastructure. For example: at the regional level, a hydropower project is a part of the local electric power supply system; at the national level, it becomes part of the energy supply system of a country; and at the international level, it is part of international compound energy grid systems. Such large-scale systems may require large efforts in collecting and storing data, which will lead to the establishment of vast data banks at all planning levels.

And at all levels there will be a continuing need to review the planning decisions of yesterday in the light of developments and evolutions of the social and economic fabric of the country, and of the needs and demands which are placed on the water resources of the region.

1.7 References


Fig. 1.1 Stages in the water resources planning process
Table 1.1 Surface water flow and supply model evaluation

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<th>Information required for applications</th>
<th>Overall rating</th>
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<td>a. Timing of water use for delivery system design</td>
<td>C</td>
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<tr>
<td></td>
<td>b. Volume of use for sizing supply facilities</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>c. Return flow volumes for drainage system design</td>
<td>B</td>
</tr>
<tr>
<td>7. Other offstream uses</td>
<td>a. Volume of industrial use for sizing supply facilities</td>
<td>B</td>
</tr>
<tr>
<td>8. Water use efficiency</td>
<td>a. Effect of increased use efficiency on return flows for evaluating conservation measures</td>
<td>C</td>
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</tbody>
</table>

**Rating Key:**
A. Modeling of the physical process at the current state of the art does a good job in supplying the needed information.
B. Information is between adequate and good.
C. Information is adequate for most purposes.
D. Information is between unsatisfactory and adequate.
E. The supplied information is generally unsatisfactory.

Source: U.S. Office of Technology Assessment, 1982
Table 1.2 Surface water quality model evaluation

<table>
<thead>
<tr>
<th>Issue</th>
<th>I: No computer, not complex</th>
<th>II: Computer, not complex</th>
<th>III: Computer, complex</th>
<th>IV: Computer, complex, operational</th>
<th>Overall level of modeling sophistication</th>
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<tr>
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<td>C</td>
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<td>C</td>
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<td>B</td>
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<td>Impacts on beneficial use</td>
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</table>

Key: A = Reliable, credible modeling may be readily used for most problems of this subissue. Some models may be suitable for regulation and design.
B = Same as C, but some models may be useful for planning and related purposes and suitable for determining relative effects.
C = Modeling of this type is not usually performed.
D = Same as C, but some models may be useful for planning and related purposes and suitable for determining relative effects.
E = Modeling of this type is not usually performed.
Overall level of modeling sophistication:
0 = No models available
10 = Routine use of models of all types

Source: U.S. Office of Technology Assessment, 1982
Table 1.3 Ground-water model evaluation

<table>
<thead>
<tr>
<th>Spatial considerations</th>
<th>Site</th>
<th>Mode types</th>
<th>Local</th>
<th>Regional</th>
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<td>Pollutant movement, if any</td>
<td>Flow only</td>
<td>Transport with reactions</td>
<td>Transport without reactions</td>
<td>Flow only</td>
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<td>Flow conditions</td>
<td>sat P</td>
<td>sat P</td>
<td>sat F</td>
<td>sat F</td>
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<td>Issues</td>
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<tr>
<td>Quantity—available supplies</td>
<td>B</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity—conjunctive use</td>
<td>B</td>
<td>R</td>
<td></td>
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<td>Quality—accidental petroleum products</td>
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<td>Quality—accidental road salt</td>
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<td>Quality—accidental industrial chemical</td>
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<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Quality—agricultural pesticides and herbicides</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Quality—agriculture salt buildup</td>
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<tr>
<td>Quality—waste disposal landfills</td>
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<td>C</td>
<td>C</td>
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<tr>
<td>Quality—waste disposal injection</td>
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<td>C</td>
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<tr>
<td>Quality— seawater intrusion</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Key:
- Rows — Issues and subissues discussed in text
- Columns — Mode types and scale of applications, e.g., the sixth column applies to a site-scale problem in which pollutant movement is described by a transport mode without transport reactions such as saturation or fracture media

Application scale:
- Site—models dealing with areas less than a few square miles
- Local—models dealing with areas greater than a few square miles but less than a few thousand square miles
- Regional—models dealing with areas greater than a few thousand square miles

Abbreviations:
- w—without
- sat—saturated groundwater flow conditions
- unsat—unsaturated flow conditions
- P—porous media
- F—fractured or solution cavity media

Entries:
- A—a reliable predictive tool having a high degree of reliability and credibility given sufficient data
- B—a reliable conceptual tool capable of short-term (a few years) prediction with a moderate level of credibility given sufficient data
- C—a useful conceptual tool for helping the hydrologist synthesize complicated hydrologic and quality data
- R—a model that is in the research stage
- U—a model that is still in the research stage
- Blank—model type not applicable to issue area.

Source: U.S. Office of Technology Assessment, 1982
2. Plan initiation and preliminary planning

This chapter is concerned with plan initiation and preliminary planning. These constitute the first stage of the water resources planning process. During this stage the identification of project needs is followed by plan formulation, which should take into account the dependency of the project on the "non-water" sectors of the economy. In the course of the chapter, some problems related to the statement of project objectives and constraints will be reviewed, along with the challenges associated with choosing appropriate personnel that will include representatives of the various agencies plus a variety of experts from many disciplines. The importance of including some mechanisms for public participation will be discussed, after which the chapter will conclude with some comments concerning preliminary selection of system analysis tools to be used in the planning process.

2.1 Problem formulation

Planning for water resources projects is initiated in response to needs that already exist or are anticipated in the more or less distant future. The nature of these needs may be very different. Sometimes one can identify the key needs, for example, protection against floods or supplying irrigation water to sustain agricultural development. However, in most cases there is a set of mutually dependent and interconnected needs; and their understanding and clear articulation are difficult. No effort should be spared to analyze in the broadest possible terms what is their real nature. Hence, identification of needs is a very difficult but at the same time very important phase of the planning process discussed in this book. There are no golden rules leading to the successful identification of needs. The planning team should think hard, use all information and evidence available, and remember above all that getting deeper into the issues under debate and understanding them better is likely to lead to redefinition of the needs at the later stages of project planning.

One of the greatest difficulties in water resources planning is that often it is initiated in response to poorly defined or ill-defined needs. Utmost effort should be made to identify the needs carefully, but sometimes one must proceed even though the needs have not been as well defined as they should be. But let's assume that we have successfully identified the needs. Subsequently, the verbally described needs must be translated into a formulation of the problem. Identification of needs and problem formulation are not the same thing. As put by Quade (1980):

Problem formulation is concerned with such things as determining the goals or objectives to be achieved by a solution, setting boundaries on what is to be investigated, making assumptions about the context, identifying the target groups, and selecting the initial approach the analysis is to take.

Translation of needs into a problem formulation is itself a process. It undergoes changes in time with respect to language and precision. Initially, problem formulation must be above all compatible with the language and precision requirements of those who are charged with plan initiation.
responsibilities. But we may encounter a very wide spectrum of different situations. Problem formulation for the initiation of a nationwide water resources plan will be less specific than, for example, problem formulation for a relatively well-defined regional water supply project. Hence, problem formulation depends on the nature and scope of the problem, on the planning level, on various constraints (technical, economic, political, etc.) that must be taken into account, and above all on project objectives.

The case of the flood protection project in the Sulm catchment in the Federal Republic of Germany (see Case Study 1) provides a good example of how needs may be translated into a problem formulation. The needs of flood protection in this catchment were known for a long time, but they really surfaced after the disastrous flood of 1970. Most important, the Audi-NSU works, which suffered flood damage in 1970 of about 10 million DM, threatened to move to another location unless its sites were protected against floods similar to the one which occurred in 1970. Consequently, a flood-protection district was established which, in cooperation with the state water administration, formulated the problem, worked out a preliminary plan, and submitted the plan for approval to the state legislature, which allocated necessary funds and authorized initiation of the planning work.

The planning levels that were described in Chapter 1 (see sec. 1.3) differ in character and scope from one country to another, but all of them require that water problems be formulated in the context of the overall economic and social aspirations of a given region or nation. Some representation of the regional and subregional levels of concern is always necessary, with its extent depending on the disaggregation of the problems. In most cases, national averages are insufficient for planning purposes, and this concerns both the supply and demand sides of water management. At no planning level should one look at the problems exclusively from the perspective of water. For example, the assertion "We have to increase agricultural production" should not lead immediately to "We need more irrigated agriculture." The real problem may be a better distribution system for agricultural products or prevention of their spoilage.

The problem formulation depends to a large extent on what is accepted as the real problem in the region or subregion in question. For example, whether sporting fishery is a problem or not depends very much on the general development of the region and the attitudes of the local population toward this type of recreational activity. Building a dam may be considered an environmental problem in a more affluent nature-and-conservation-oriented society, while such concerns will be less critical in another situation, such as when a dam contributes to the production of badly needed food and fibre.

Problem formulation is always subject to several constraints. Political (administrative) and hydrologic boundaries usually do not intersect, time and budget allocation for problem solution are often limited, various regulations significantly narrow the range of planning options, water demands are often exogenous to the planning process, skilled and professional personnel are unavailable - these are just a few of the constraints that always impact problem formulation. The appropriate consideration of each of any such constraints brings problem formulation closer to becoming viable and implementable.

Several issues related to
problem formulation are discussed in subsequent sections.

2.2 Dependency of plan formulation on "non-water" sectors

After the needs have been identified and the problem formulated, one can start the preliminary formulation of the plan. Because a plan is concerned with water, it should not necessarily be considered a "water" project per se. The solution may in fact be only tangentially related to water control and management. It is thus very important that all possible competing or complementary aspects of "non-water" sectors of the economy be considered before the preliminary formulation of a water plan. This pertains to such questions as hydropower vs. thermal power developments, navigation vs. railroad transportation, and structural flood control measures vs. nonstructural floodplain management. In general this addresses the issue of substitution and trade-offs. The interface and interdependence of water and related land resources with other sectors of the economy should be recognized in preliminary project formulation.

To what extent water resources management itself can be treated as an individual sector of the national economy is another question which has no clear answer. Even in centrally planned economies, water management sometimes does not have a sector status - water management responsibilities are distributed among several ministries, such as those for agriculture, energy, and public works.

Water resources planners must often base their plan formulation on imperfect information concerning other sectors of the economy. For example, water resources planners in Israel formulating the Eastern Negev Project (see Case Study 2) stress that the development plan and schedule for industrial activities were uncertain, the future cropping patterns were dubious, and the overall pace of physical development of the region was not stated clearly enough. Such difficulties should be explicitly recognized in the preliminary project formulation phase.

2.3 Statement of project objectives

One of the most important parts of preliminary plan formulation is a clear statement of project objectives. It should be remembered, however, that in most practical situations, objectives cannot be taken as given. As pointed out by Hitch (1961), it is usually impossible to define appropriate objectives without knowing a great deal about the feasibility and cost of achieving them. And this knowledge must be derived from the analysis. The greatest difficulty in starting with given objectives is the fact that most often they are multiple and conflicting, and that alternative means of satisfying any one objective are likely to produce substantial adverse effects on another. Nothing but rigorous quantitative analysis can tell whether a particular objective makes sense or not - whether it is feasible, how much it will cost. Such analysis and ultimate choice of socially relevant project objectives requires judgment both on the part of the water resources planner, and on the part of other participants in the planning process, e.g., the politicians. This is stressed by Major (1977), who underlines that "much of the confusion and debate about water resources projects that have been proposed in the recent years has arisen because the planners were not developing design options responsive to the objectives of the political process." The perception of project objectives by the public at large and other constituencies is equally important.

The goals and objectives are stated differently at the various planning levels. The ones at the national level - for many good reasons that are not about to change - tend to be global (e.g., to
enhance national economic development, to enhance social well-being, to enhance quality, and to enhance regional economic development). Moreover, they do not detail the conflicting issues. They are intentionally as encompassing and as comprehensive as possible to ensure broad support by the various constituencies and stakeholders. In this respect, one should keep in mind the "horse-trading" process that is so dominant when it comes to the water resources planning process. The art of negotiation and compromise is an integral part of that process, and for negotiations to succeed, the parties must start with an acceptable agenda of project objectives that can be modified during the negotiations. Having reached agreement about the general project objectives, more focus can be centered on specific objectives and their translation into design criteria. These criteria require definition of the measures that will be used to assess to what degree individual objectives have been met.

The specific project objectives usually coincide with one water management purpose or several, such as water supply, protection against floods, development of navigation, hydro-power production. The case studies presented in the Appendix of this book provide an illustration of how differently specific objectives may be stated. The only explicit objective of the Eastern Negev Project in Israel (see Case Study 2) was satisfaction of the increasing water demands at the least overall cost. The objectives of the Maumee River Basin Study in the U.S. (see Case Study 4) were to protect land resources, to reduce erosion and sedimentation, to improve water quality, to protect fish and wildlife habitats, to enhance outdoor recreation opportunities, to reduce flood damages, and to meet water supply needs. The objectives of the Vistula River Project in Poland (see Case Study 6) were to formulate a water resources development (investment) program capable of meeting water management tasks (primarily water supply, flood control, and water quality control) that were projected to the years 1985 and 2000 (15 and 30 years time horizon, respectively). The objective of the Adelaide Water Resources Study in Australia (see Case Study 5) was to make recommendations for a program of works construction and for particular operating policies, in order to provide a water supply for metropolitan Adelaide over the next 30 years.

Even these few examples of project objectives show that, depending on the character and the scope of the project, objectives can be stated in very different ways.

2.4 Project constraints

The evaluation of project objectives leads to alternatives, while constraints restrict alternatives and reduce their number. However, from an evaluation point of view, constraints often have a function similar to objectives. As pointed out by Simon (1964):

It is doubtful whether decisions are generally directed towards a goal. It is easier and clearer to view decisions as being concerned with discovering courses of action that satisfy a whole set of constraints. It is this set, and not any one of its members, that is most accurately viewed as the goal of the action.... Whether we treat all the constraints symmetrically or refer to some asymmetrically as goals, is largely a matter of linguistic or analytic convenience.

When a distinction between objectives (goals) and constraints is made, it is usually based on the misconception of accepting the constraint as an absolute restriction. Constraints must not be treated as sacredly inviolable. They must be scrutinized from many points of view as the analysis proceeds and technical possibilities emerge, and their roles should be subject to change.
Constraints generally considered in water resources planning vary widely. They may be of technical and economic nature, but also important and often overlooked or underestimated are institutional and cultural constraints which rule out certain project alternatives. In general, all constraints should be explicitly specified and open to debate in the plan initiation phase to avoid controversies that may surface at later stages of project planning or implementation.

The case studies in this book specify a wide spectrum of different constraints. Time, funding, technical, and technological constraints are most common, but legal constraints are also mentioned quite often. For example, the national laws in the United States at the time of the Maumee Study placed important water quality responsibilities in the hands of the states. As a consequence, the states were not prepared to draft a water quality management plan for an entire basin. Quite often the planners are also constrained by the requirement of using only existing data, irrespective of how adequate the data base is for the preparation of a plan (see Case Study 3). Lack of adequate data, existing structures, and plans of other agencies are also quite common constraints.

Some constraints are permanent and can never be violated, while others are binding in the short run and may be changed by the passage of time or removed by invention or technological improvement. Thus, some constraints are firm, others less so. But irrespective of the nature of a particular constraint, it is the professional responsibility of the systems analyst to point out the influence of its marginal cost on the project outcomes. If the systems analyst is told that something he believes to be relevant should not or cannot be considered, he must clarify to the decision-makers what the consequences might be.

2.5 Agencies and personnel involved

The organizational structure the planners are faced with when initiating a water resources planning effort is more often than not a "geological" accumulation of past organizational compromises (Wiener 1972). Sometimes the existing structure fits the objectives of the project; sometimes it must be bypassed and a new planning entity be created. No hard and fast rule determines what is best for each specific case.

If a national agency charged with water planning is already in existence and the project is not of a very local scale, this agency is the one which usually takes the lead and prepares the plan. This was the case of the Vistula Project in Poland (see Case Study 6), where the consulting firm operating within the framework of the National Water Authority was charged with preparation of a plan in cooperation with about 40 research institutions representing all ministries concerned. The development of planning methodology was assigned to a specially formed research team of about 20 specialists who cooperated closely with an international panel of United Nations Development Programme (UNDP) experts throughout the entire duration of the project. UNDP experts assisted also in the preparation of the Upper Mures Project in Romania (see Case Study 9), which was assigned to a national water research and design institute (part of the Romanian National Water Authority) reporting directly to the Permanent Executive Body of the Upper Mures Project. The Eastern Negev Project in Israel (see Case Study 2) was prepared by the national water planning organization, although the project was relatively small and two water resources engineers, one programmer, and one student were sufficient to take care of the system design.

Somewhat different organization may be encountered in other countries. For implementation of the Study of Drinking Water Supply
in the province of South Holland in the Netherlands (see Case Study 3), distinction was made between governmental planning and technical planning. The first one has been dealt with by the Steering Committee, whose members were top administrators of central and provincial governments. The technical planning has been carried out by several research institutions under supervision of the National Institute for Water Supply. Almost all the people carrying out the study have academic degrees. The disciplines represented vary from mathematics and engineering to biology, and the group included experts on the recreational behaviour of the local population.

For the Maumee River Basin Study in the USA (see Case Study 4), the Great Lakes Basin Commission formed a planning board, with members from three states and four federal government agencies. In addition to the relatively highly skilled personnel in the state and federal agencies, the Commission was assisted by a small research team from a university.

The only agency directly involved in the Metropolitan Adelaide Water Resources Study in Australia (see Case Study 5) was the Engineering and Water Supply Department of South Australia, responsible at the time of the study to the Minister of Works of the Government of South Australia. The development interacted with the River Murray Commission, a body on which the government of all the states of South Australia involved in the study were represented as well as the Federal Government of Australia. The skilled personnel involved in the planning process were engineers and an engineer-economist of the above-mentioned Department.

The Susa Research Program in Denmark (see Case Study 7) was led by the Danish Committee for Hydrology. The subproject concerning management of water resources was carried out by three organizations - a research institute (university), an institute for applied research (commercial basis, nonprofit), and a private, government-supported agency (nonprofit).

Planning a system of flood protection reservoirs for the Sulm Catchment in the FRG (see Case Study 1) was carried out by the local State Water Administration Bureau, which maintains a staff capable of handling all technical and administrative tasks. The Bureau was assisted by a small team of university research people.

The great variety of organizational involvement is evident, and the examples cited above are just some of the many possible arrangements. Most of the agencies were assisted in the planning process by external experts, mostly from universities. This is understandable, since government agencies in many countries have developed a specific mission or missions over the years. To ensure the generation of a sufficiently comprehensive plan and to provide for evaluation of several project options, a mix of agencies is preferable, usually with one of them entrusted with the leadership and coordination responsibilities.

2.6 Selection and utilization of experts

In the plan initiation and preliminary planning phase, it becomes necessary also to ensure that contributions are made by many different experts. The multidisciplinary nature of water resources planning necessitates that interdisciplinary interaction should take place among them. Usually the results are more multidisciplinary than interdisciplinary, meaning that although there is interaction, it tends to take the shape of a presentation of results by the individual experts as seen in the light of their own expertise.

Some of the most important prerequisites for the success of an
interdisciplinary study are (1) developing mutual trust among the experts and (2) helping each expert to realize that within his or her own discipline he or she can contribute to the overall study effort. Thus each recognizes that his or her contribution is being listened to as worthwhile. Additional conditions for project success include the mutual development among experts of a spirit of cooperation and the ability to overcome a natural bias among the disciplines so that different or opposing points of view, approaches, and beliefs will be tolerated. The time needed for these conditions to develop and mature and the fact that almost every expert joins the team with his or her own preconceived notion of what constitutes a planning study may explain why, during the preliminary phase, much time may be spent in philosophical discussions that often seem trivial and endless. It is here that well-developed and acceptable guidelines for regional or river-basin planning would have the most impact on streamlining such costly, time-consuming debates.

Usually there are two major groups of experts involved in the plan initiation and preliminary planning phase. First, there are experts who are capable of formulating the system concepts. They must interact with other groups who have expertise in water supply, industrial water use, irrigation, hydro-power production, forestry, and the like. The systems analysts and disciplinary experts fully understand the project purposes and objectives. This is especially important when the disciplinary experts identify constraints that reduce the modeling freedom of the systems analysts. It is important also to consult experts who are not project-specific, such as lawyers, biologists who investigate rare species, archeologists, landscape architects, etc.

The business of whom to select is in part determined by the locally available expertise and the scope of the project. Experts should be carefully selected, and inquiries to their former customers and evaluation of their previous work may be very useful and advisable. The most important expert to be selected is the project leader. He must not only be an expert in water resources planning, he must also be a leader. His talents and personality are of crucial importance to the successful completion of the planning activities.

2.7 Public participation

For the purpose of this section, the word public refers to an individual or a group not having the governmental decision-making authority. Public participation refers to the activities of such individuals or groups in trying to influence decision-making. Public participation should not be a one-way street. It should not only be a way of ascertaining different views, but it should also provide those whose interests may be affected an opportunity to learn about the decisions being made. It is important, however, to find a way to insure that expression and consideration of public viewpoints do not improperly impede the decision-making process. According to U.S. sources (National Water Commission 1973), determining the role that public participation should play in water resources planning requires discovering (a) the limitations inherent in public participation, (b) the requirements that must be met to ensure adequate participation, and (c) how that participation should be structured.

In several countries, water resources management and planning is the responsibility of specialized agencies which represent the interests of all water users and the public at large. The public is, therefore, represented in the planning process by virtue of the fact that representatives of several constituencies serve on practically all governmental and local
administration agencies. Such agencies, of course, must listen carefully to the concerns and opinions voiced by the different interest groups that provide this input into the planning process. Concerning the public at large, efforts should be made to keep it informed about the progress of the project by presenting in the mass media (or even at special meetings, such as are held in the Netherlands) summaries of the "work to date." Project results should also be disseminated for public scrutiny and comment through the various agencies involved in the study.

In some cases, however, special groups are formed, such as the Citizens' Advisory Committee for the Maumee River Basin Study in the USA (see Case Study 4), which was a formal entity with an appointed membership. These appointments were made through various civic groups, such as the League of Women Voters, the Sierra Club, etc. With such a strong backing from a broad civic constituency, a formal mandate to participate in the planning process, and a budget allocated from the project planning funds, the Committee was vocal and influential. There are other ways equally effective, e.g., the citizens' participation done in the FRG.

Although the forms of public participation may be more or less formalized in different countries, it is important, especially in the plan initiation phase, to expand it as much as is practical and reasonable. It should be recognized that there are no firm a priori grounds for believing that the engineers of a water authority or representatives of any other governmental agency know fully what the public wants and what is "best" for the public.

2.8 Preliminary selection of systems analysis tools

The planning process should be driven by the goals, objectives, and issues of concern and not by specific planning methodologies that the planners are acquainted with. According to Miser (1982), six principles of that choice may be enunciated. Analytic tools should be chosen that are

1. appropriate to the problem and to the prospective solutions that may emerge.

2. matched appropriately to the available data, since an attractive method that calls for nonexistent data cannot yield trustworthy results.

3. internally consistent (the sophisticated analysis of one part should not be bludgeoned by hazy speculation in another).

4. balanced in detail and accuracy (if one enters with order-of-magnitude estimates, one is seldom entitled to five-figure accuracy in the results, or, if accurate estimates are combined with very questionable estimates, this fact should be reflected in how the results are presented).

5. appropriately interdisciplinary in the light of an appreciation of the problem with which the work began and is being continued.

6. appropriate, if at all possible, to the process of presenting the findings that will emerge at the end of the planning study (the client will surely not want to poke into details, but some understanding of the analytic tools has persuasive value for many users of systems analysis results).

Additional advice is offered by Raiffa (1982) concerning the use of models in systems analysis and planning efforts:

In modeling reality for policy guidance there are a host of options to consider. First of all some advice: Beware of
general purpose grandiose models that try to incorporate practically everything. Such models are difficult to validate, to interpret, to calibrate statistically, to manipulate, and most importantly to explain. You may be better off not with one big model but with a set of simpler models, starting off with simple deterministic ones and complicating the model in stages as sensitivity analysis shows the need for such complications. A model does not have to address all aspects of the problem. It should be designed to aid in understanding the dynamic interactions of some phase of your problem. Other models can address other phases.

Although selection of methods and systems analysis tools to be employed for project planning should not be done too early, the plan initiation and preliminary planning phase should involve some preliminary work concerning their choice. The extent of this work depends on the character and the scope of the project and on several other factors, but most often there are initially a few (i.e., not too many) individuals who are familiar not only with the subject matter of the project in question but also with systems analysis and its tools. They should examine what analytic methods related to the project are readily available (including examination of computer hardware and software), what adaptations and new methodological developments might be necessary, and what manpower and financial and computational resources are available to do the job. The data available and time constraints are important factors in such an analysis. Final selection tools and methods to be used in data processing, manipulation, and interpretation is almost always a compromise between what one wants to do and what one can do under given circumstances. Frequently it is useful to make some back-of-the-envelope calculations based on simplified assumptions just to get an idea of what can be expected if more elaborate methods are to be used.

Almost all case studies examined in this book indicate that the selection of systems analysis tools and development of the methodological approach will be accompanied by some disputes, especially if application of some of the more advanced methods is considered (e.g., the surrogate worth trade-off method applied in the Maumee River Basin Study). However, even in case of considerable disagreement on the methodology to be used, such disputes can have a positive effect on the ultimate outcome of the analysis.

What are the major questions to be addressed in the preliminary selection of systems analysis tools? One of the most critical questions is how to handle project uncertainties due to the short- and long-term variability of water resources (primarily precipitation and streamflow). But the uncertainty issue is not limited to hydrologic processes: it relates also to project objectives, water demand projections, and several other factors embedded in the socioeconomic context of a given project. Another typical question is whether alternative project solutions should be examined and compared by simulation, or the "best" solution be directly identified by application of one of the optimization techniques. In case of more complex planning efforts, simulation is usually a more preferable approach; however, quite often simulation is coupled with some kind of scalar (single-objective) or vector (multiple-objective) optimization, e.g., for optimization of water resources allocation at each simulation step.

The problem of the systems analyst is to find that particular tool or set of tools that will correspond best to the project needs.
2.9 References


3. Data collection and processing

Chapter 3 is concerned with data collection and processing, which constitute Stage 2 of the planning process. In this stage the data needed for the project should be collected and their quality and quantity evaluated, and decisions should be made on the collection of additional data concerning the hydrologic regime of the water bodies, water quality, water use, and alternative ways of project implementation and its operation as well as demographical, economical, and ecological information.

The data collection process requires listing of sources of data, exploration of these sources, inquiries about other possible data sources, evaluation of data quality, and tabulation of data for their final processing. This process involves many experts, because the data collected must be purpose-oriented. The purpose must govern the type, the accuracy, and the time horizon of the data. For example, data needs for national or regional long-term water resources planning are discussed in the handbook for national evaluation of water resources assessment activities (Unesco/WMO 1981).

3.1 Specification of data needs

When the plan initiation and preliminary planning result in authorization to proceed further, the planning effort enters the data collection and processing phase. Always some data are already available from the preliminary planning analyses, but in most cases they are insufficient for generation of project alternatives and their evaluation. At this point a more complete data base is needed (concerning hydrologic data see, for example, Andrejanov 1975). In principle, there are three possible situations concerning collection of additional data. First, we collect whatever is already available and pertinent to the project goals without initiating any specific field measurement programs. Second, it may be found that the available data are very limited and further planning requires that additional observations and measurements be made. In this case the probable opportunity loss of delaying the project until enough additional data are collected must be carefully evaluated, taking into account what risks of project inadequacy can be accepted. Finally, the third possible situation is a mix of the two other: the available data base is supplemented with some additional information collected in the field by means of ad hoc and highly selective measurement programs of short duration.

To what extent an actual situation corresponds to one of the three possibilities mentioned above depends very much on the agreement of the experts involved in preparation of a plan. As pointed out in Chapter 2, expert opinions concerning data needs may vary quite widely. Experts with know-how in the technical disciplines may press for much more detailed data than is required by the project goals, which are understood better by the systems analysts. On the other hand, systems analysts must remember that their methods can hardly be used to prescribe appropriate courses of action if they are not based on an adequate description of the way the system works. Data availability places restrictions on the analytic methods that can be used in a specific situation. Hence, the data and their accuracy must be subject to open discussion by all concerned. Initially, these discussions should be kept at a strategic level, remembering above all that
evaluation of data needs is a process in itself, and several of the questions concerning data adequacy cannot be answered prior to critical appraisal of the results of the first model runs.

The advantages of mathematical models are recognized in many countries all over the world. The models, however, cannot be fully effective without adequate data to support them (model development, calibration, validation, and ultimate application). This is why the data-gathering process should be related more directly to the needs of models. Subsequent to the acceptance of the project objectives and methodology by all experts on the planning team, the data contributors must understand and accept that the systems analyst (the model builder) sets the data requirements.

3.2 Data adequacy

Virtually all hydrologic and nonhydrologic data can be considered to be inadequate in some respect. The question is, how inadequate is inadequate, or, alternatively, how adequate is adequate? (Watt and Wilson, 1973). To answer this question it is necessary to define the purpose for which the data are to be used and the consequences of various degrees of data imperfection. In other words, assessment of data sufficiency should be based not only on probabilistic statements related to sampling and parameter uncertainty errors but also on an evaluation of how sensitive are the key project parameters (in economic and overall performance terms) to possible changes in the data base accuracy and scope. From a conceptual standpoint, the data can be considered adequate when the marginal cost associated with improving the data is equal to the marginal benefits attributable to such improvement. As a practical matter, however, implementation of this straightforward concept is very difficult because of uncertainties in the evaluation of future benefits.

It is worth noting that adequacy of data is also a function of the methods used for planning and decision-making. If a project is planned to accommodate future adaptations to revised objectives and new information, larger errors in the estimates of key project parameters may be tolerated. If no such accommodations are included in the plan – a common approach by those who like to solve problems once and for all – much smaller errors should be allowed than in the case of flexible, adaptive planning (Yevjevich 1973).

When the general circumstances are such that a plan is needed, it is the role of the water resources planner to develop the best plan possible for the available data. It is true that many plans for water resources projects, particularly in developing countries, are proposed at times when the hydrologic and nonhydrologic data base is far smaller than what would be desired for an effective analysis. Nevertheless, while the planner may properly advise as to the risks involved in planning with inadequate data, he will rarely be in a position to suspend planning activities until more detailed data are available. Quite often it is difficult to postpone a project because of political pressures or the existence of problems requiring immediate action. In such situations it is always worth considering the possibilities of implementing the project in stages, although this always incurs additional cost, even if staging is technically feasible (sometimes it is not). The other possibility is to design a project in such a way that eventual losses due to the use of imperfect data are simply minimized.

As a matter of fact, the issues discussed in this section are not only the question of data adequacy – it is a "wait a while" syndrome in anticipation that uncertainty about some of the crucial factors influencing project design will be reduced. But usually waiting will not improve things and, with the
passage of time, new clouds of uncertainty emerge.

The case studies appended to this book indicate that in many planning efforts only existing data are used. Quite often they are subject to intensive processing that has as its purpose a better evaluation of the risks due to all types of uncertainties, including those due to imperfections in the project data base.

3.3 Data acquisition

As already mentioned in the first section of this chapter, the term data acquisition has different connotations that depend on the actual situation concerning data availability. The methods of field collection of data on the elements of the hydrological cycle and related factors fall outside the scope of this book. Several manuals, including those published by the World Meteorological Organization (e.g., WMO 1972), are available on this subject. Moreover, in most countries collection of field data is a responsibility of specialized hydrometeorological services, and they should be consulted if the need for additional field data arises. The acquisition of hydrologic data means, above all, the location of the data sources including inspection and evaluation of these data as to their suitability and sufficiency for specific planning effort.

Although it is an arbitrary division, hydrologic data sources may be divided into usual and unusual ones. The usual data sources include hydrological and meteorological yearbooks, reports by various types of experimental and research stations, records kept by regional water authorities, and the like. It should be remembered that many organizations are often almost completely unaware of data collected by others; even governmental agencies often know very little about data collected by other governmental agencies and almost nothing about data compiled by nongovernmental institutions.

Generally it is advisable also to search for unusual data sources, such as newspaper accounts, older residents' memories, tree rings, glacier deposits, etc. For example, high-water marks along rivers may be useful in delineating flooded areas. Such marks, if taken carefully, may be used with other data to compute peak discharges of the stream by indirect methods (WMO 1974).

Collection of hydrologic data should not be limited to dynamic processes such as streamflow, precipitation, evapotranspiration, groundwater flow, or soil moisture changes; static physical basin characteristics should also be taken into account (e.g., characteristics to be used in rainfall-runoff models). Basin characteristics are usually grouped into three categories: (1) topographic, (2) soils and geology, and (3) land cover and land-use. Information on these characteristics is commonly available from the various types of maps (topographic, soil, land cover, etc.) that are available through appropriate governmental agencies. When no suitable maps exist for an area, it is recommended to check whether some remotely sensed data are available. These data may include conventional large-scale black-and-white aerial photographs, high-altitude color-infrared photographs, and Landsat multispectral imagery. Several manuals are available to assist in acquiring different information from remotely sensed data (e.g., Avery 1977).

Although collection of hydrologic data presents many problems, acquisition of water-use data is usually a much more complex task. Problems stemming from the scarcity of water-use data are serious, especially at the individual activity level (a farm, industrial enterprise, or household). As things now stand, it is widely if not universally true that these data, if they exist at
all, can be collected only from the water-users themselves.

As pointed out by Kindler and Russell (1984), water-use data requirements vary according to the approach taken toward representation of water use in the planning effort. There are two broad approaches used. The first one requires data on a set of several inputs to each water-use activity (including the water itself), each activity's associated prices and costs, and a set of total outputs, including outputs of pollution, with their associated prices and costs. Such data can only come from repeated observation of the same water-user over time (say, monthly totals over several years) or simultaneous observation of many users of the same sort at the same time (say 50 or so users). For self-evident reasons the first source is known as a time series, the second as a cross section. Under certain conditions and using correct techniques, it is possible to pool the time series and cross-sectional data, so that several inadequate data sets may be combined into one with enough size and variation to be helpful (see, for example, Johnston 1972). But, under all circumstances, extreme care must be exercised in the interpretation of the available statistical information, especially the price-quantity data (see Kindler and Russell 1984 for more detail).

The second approach is determined by the process for which the water is used. It requires data on what is going on within and among the many unit processes of a single water-use activity. This approach amounts to a summation of all individual water demands which can produce a large number of alternative activity designs. These designs in turn can be used to define water-use relations and unit water-use coefficients for specific activities such as steel rolling, paper production, household water use, and the like.

Water resources planning needs both hydrologic and nonhydrologic (among them, water-use) data. It should be recognized that these two broad data sets should be mutually consistent if they are used in the same model. Spending unjustified time and resources, for instance, on the refinement and improvement of the hydrologic data base at the expense of the depth and scope of other nonhydrological data should always be avoided. In other words, do not try to improve one set of data if another set of equal importance to the model, for whatever reasons, is bad.

One of the common problems which make data acquisition difficult is that hydrologic data are always collected within the watershed boundaries, while nonhydrologic data usually refer to different spatial units that follow the political and economic subdivisions of the area under consideration. Adjustments must be made to make all project data compatible in time and space.

3.4 Data quality control

In this chapter, quality control connotes the steps that should be taken to ensure that data of good quality are used in the preparation of a plan. These steps usually include preliminary checking of data and detection of errors by internal consistency checks. The preliminary checking must ensure the overall correctness of indicative information; simple geographical and arithmetical checks should be applied to see if the data provide an appropriate long-term picture of past events concerning both water availability and water use in the region under consideration. In this process, data gaps which may affect outcomes of the plan should be identified, and the possibilities of filling such gaps by estimation or interpolation should be analyzed. It should be noted that frequently such analysis is too complex to be done manually, and not much preliminary checking can be done before the data are transferred into the computer and prepared for machine processing.
Data inconsistencies are most often due to measurement errors or measurement being credited to the wrong time, but caution is urged in making data adjustments too easily without solid reflection as to the possible sources of error.

Data quality control should also include checking how representative are the data for the current hydrological conditions in a given basin. This pertains especially to streamflow series in a basin subject to large-scale man-made changes, e.g., by deforestation or strip mining. Although relatively long records may be available, they can no longer be considered representative unless man-made changes in the basin have been appropriately taken into account, which is usually a very difficult task.

Techniques for quality control of data differ for various data types. For example, the quality of streamflow records for a given stream may be checked by comparing them with concurrent records for nearby streams and with concurrently recorded other hydrologic parameters, such as precipitation and temperature (WMO 1974). The routing of flood hydrographs is often used for checking flood discharges recorded at different profiles along the same stream. Groundwater level fluctuations may also be used in quality control of precipitation and streamflow data.

The data accuracy requirements should be consistent with the quality and sampling adequacy of the data used and with the degree of accuracy required by the specific analysis. In many instances, graphical and relatively simple computational methods are sufficiently accurate for the data and purposes involved.

3.5 Data processing and screening

In many cases it is necessary to process collected data into a form compatible with requirements of the methods adopted for preparation of a plan. Data processing usually includes statistical analysis, such as computation of means, standard deviations, correlation coefficients, lag times, parameters of frequency distributions, durations, and other statistical parameters describing both the temporal and spatial structure of the processes that determine water availability and water use in a given region. Several of these statistics are used for filling data gaps by regression and correlation methods. Data processing also often includes conversion of data into compatible time scales and consistent measurement units (e.g., conversion of mean flow intensities into flow volumes over a period of time).

One of the purposes of statistical data processing is screening of data to obtain homogeneity among data of various kinds. Screening generally has three purposes. One purpose is to reduce the data to the standard base period of record. This is necessary because a frequent problem in generalization of hydrologic and nonhydrologic data stems from the fact that they refer to different periods of record. Attempts to compare records without making appropriate adjustments will mix variation in space with variation in time. The second purpose is to eliminate or reduce the effects of inconsistencies in data records. Simple examples of such screening procedures are a double-mass curve analysis (WMO 1974) applied to detect change of exposure at a precipitation station and a time series analysis used to evaluate how accurately streamflow records represent the natural runoff of a catchment area. The third purpose is data reconciliation, since data from different sources relating to the same variable may not be the same or even compatible. Therefore, one must reconcile the differences and come to an explicit decision about what to use as planning data. Examples include differences among hydrologic data collected.
concurrently by different hydrologic agencies, population projections made by application of different methods or according to different spatial units, or monthly data that do not add up to same total as data from a different source that gives the data as an annual basis.

The data processing and screening needs are highly situation-dependent, and the level of effort is greatly influenced by whether or not appropriate computer facilities are available.

3.6 Data information systems

Data systems vary considerably, depending on the character and scope of the specific planning effort. For long-range planning, steady accumulation, analysis, and display of data over periods of hours, days, or months is sufficient, while operational planning requires more or less immediate receipt, processing, and retransmittal of information. Therefore, while serving one functional need well, a data system does not necessarily serve another.

What type of data information system is advisable for a given plan depends very much on the level of effort, access to computer installations, availability of data management experts, etc. A plan-specific consciousness should exist at all times in developing a usable data information system that will suit most adequately the needs of the water resources planner in the specific context. Sometimes the plan involves a very large amount of data, and the task of data handling, compiling analytical results, and converting them to fit plan requirements cannot be coped with by conventional methods. Evaluation of the data collected may also be a problem — dealing with conventionally tabulated values in high numbers means always an unjustified expenditure in terms of cost, accuracy, and time. In such cases, the data can only be handled with the aid of computer data processing, and the need for a plan-specific data base or data-base system may even arise.

The term data base was introduced into the theory and practice of data management by the end of the 60s. A data base connotes a collection of various types of data files, including relations among these files, data aggregates, and data items. But, as happens often to a fashionable term, many organizations started calling their files data bases, changing only the name without giving notice to such fundamental data-base properties as exclusion of data redundancy, provision for data independence and protection, precise definition of mutual relations among different data, and provision of real-time access to stored data. The importance of these properties has grown considerably with the development of better software for data processing and management.

Data-base systems are sometimes called data banks; they include several data bases stored on peripheral storage devices and collections of computer programs for such typical data processing operations as data search, retrieval, updating, input, and deletion. In addition (or alternatively), the system may include on-line users who interact with data bases from remote terminals.

3.7 References


4. Formulation and screening of project alternatives

This chapter is concerned with the formulation and screening of project alternatives; these usually constitute the third stage in the water resources planning process. This stage includes the classification of project alternatives, the actual generation of project alternatives, checking that these alternative plans are compatible with other plans, checking that the models used are calibrated and credible, and using hierarchical and multiobjective analysis to screen the various project alternatives. This stage leads to the formulation of selected alternative projects and to the evaluation of their relative advantages and disadvantages.

4.1 Overview of the evaluation of alternatives stage

The planning and management of water resources and water-related land resources is both an art and a science, and it involves the utmost utilization of many disciplines. In the planning process, forecasts and predictions must be made under risk and uncertainty. In addition, decision-makers must analyze the various alternative policies that often reflect conflicting economic, societal, environmental, and political forces. A water resources plan has a viable chance of being implemented only if it addresses itself to the multiple objectives and goals of the region concerned. With ever-increasing public awareness of and participation in the decision-making process (as evidenced by the many citizens' advisory boards, active public hearings, etc.), the planning task has become even harder. Consequently, methods and approaches from system analysis, particularly those that are designed to help decision-makers choose among alternatives, have been increasingly used in water resources planning and management.

When Stage 1, plan initiation and preliminary planning, and Stage 2, data collection and processing, have been completed, a plan is ready for Stage 3, which encompasses the formulation and screening of project alternatives. In this stage, several steps must be followed. These include

- The verbal articulation and quantification of
  - objectives
  - constraints—hydrological, institutional, financial, etc.
  - measures—structural and nonstructural
  - the system's (region's) components (e.g. subbasins and subareas)
  - the system's projected demands:
    - municipal and/or domestic
    - industrial
    - agricultural
    - fish and/or wildlife habitat
  - the system's projected supply capabilities:
    - groundwater
    - surface water
    - interbasin water transfer
    - reclaimed water
    - etc.
  - water quality problems and/or potential contaminations
* flood problems and/or needs for flood protection
* recreation
* hydro-power
* etc.

b) concept analysis based on the following steps:

* generation of several alternative plans with Pareto optimal solutions (i.e., a solution where one objective can be improved only at the expense of degrading another objective) and their respective trade-offs
* evaluation of the alternative plans
* conduct of risk-benefit analyses
* conduct of impact analyses on the alternative plans

When Stage 3—the formulation and screening of alternatives—has been completed, it must be decided if more data are needed. If possible, decisions on specific models should be postponed until any needed additional data are acquired or until a data base becomes available.

When plan alternatives suitable for potential implementation have been selected, this marks the end of the prefeasibility part of the study. Toward the end of Stage 3, the political process has to take over. In particular, the following steps should be taken:

* conduct of public hearings, as appropriate, to generate support for the plan by the public and other important constituencies
* evaluation of comments and suggestions made by the public and the agencies
* conduct of multiobjective analysis
* discussion of the results with decision-makers at the various levels, as appropriate
* evaluation of the decision-makers' preferences, with appropriate response by making modification(s) to the plan

The final result of this process is the political decision to continue or discontinue the planning activity. If the decision is to proceed, the next steps include

* authorization to complete the planning process
* appropriation of funds (could be the same as the authorization, in some countries)
* designation of an agency (or agencies) to complete the planning process
* formation of a regional planning entity (as appropriate)

4.2 Classification of alternatives

In the planning process, all plausible project alternatives should be considered—feasible and nonfeasible, structural and nonstructural, water and "non-water." Although some may view the study of nonfeasible alternatives as wasteful, important and valuable information might be gained from such effort: for example, a sensible measure or plan that happens to be at the time politically or institutionally infeasible can shed light on the cost associated with existing institutional impediments and might indicate specific ways for removing or alleviating such obstacles. Non-water alternatives often constitute an integral part of what
is commonly known as a water alternative package; for example, land transportation might be considered as an alternative to navigation. Technical constraints may also indicate the selection of alternatives; for example, a dam site might have an excellent rock foundation but would require major work in relocating people or rerouting transportation lines, while another location might require extensive foundation work.

Furthermore, it must be realized that there are often different alternatives to accomplish the same objective. For example, flood protection can be achieved by retention structures, by flood levees, or by zoning to prevent settlements in flood-prone areas. On the other hand, alternatives for water supply include the use of ground or surface water or both (conjunctive use). Also, storage for a water supply may possibly be provided either behind a large dam in the main river or behind many smaller dams located in the tributaries. Hydro-power generation should be considered within a broader economic scale, with nuclear or fossil-fire generating units considered as part of the system. Such considerations commonly lead to the use of pumped storage plants, where excess energy during low-consumption periods is used to pump water into a temporary storage at high elevation, from which it is released through turbines at peak-demand hours.

Although a classification of alternatives can be helpful for pedagogical purposes, the planner should be careful to avoid simplistic dichotomies in classifying alternatives—for instance, water vs. non-water alternatives—or similar simplistic classifications of water issues, such as ground vs. surface water, water quantity vs. quality, water supply vs. demand, etc. The successful operation, maintenance, and management of any water resources system should ultimately transcend the barriers created by these artificial classifications and make use of the attributes of all plan components and the system's potentials.

4.3 Generation of alternatives

During Stage 3 of the planning process—the formulation and screening of project alternatives—several possibilities exist in terms of generation and screening of alternatives. These include the following.

(i) A small number of alternatives leads to elimination of the screening step.

(ii) A large number of alternatives necessitates the use of mathematical models (this is often the case for long-range and regional planning).

(iii) A large number of alternatives requires the use of hierarchical screening in stages, with an increasing rigidity of selection and/or exclusion criteria being adopted as the screening process proceeds. This procedure also requires that planning philosophies be agreed upon by all concerned parties.

It should be clearly noted that Stage 3 and Stage 4 (development of final study results) are not mutually exclusive, and often some overlapping occurs. In particular, the discussion and arguments that take place in Stage 3 should be recorded so that activities at Stage 4 can be appropriately guided. This is even more critical if a new team works on Stage 4.

The planner who is engaged in the process of generating alternative projects may differentiate between cases with a relatively modest number of discrete alternatives and those with a very large (infinite and continuous) number of alternatives. In the former case, the alternatives are primarily generated directly through brainstorming and by perturbation of previous alternatives. In the
latter—the continuous case—the use of models is almost imperative, and the role of the analyst and/or the planner and the decision-maker is to decide which of the system's objectives should be kept as such and which should be considered as constraints.

The use of mathematical models in the generation of alternative plans is most important and valuable when trade-offs are considered. The hierarchical approach, which allows the aggregation of several models into an overall model, can be very helpful here. For example, linear programming allocation models can be integrated with dynamic programming capacity-expansion models, and further integration can take place with streamflow simulation models, etc.—all within a hierarchical multiobjective framework.

4.4 Model credibility and model calibration

Model credibility and model calibration imply two different but related issues. The credibility of a model refers to the acceptance of the model, while model calibration connotes estimation of model parameters.

Models always represent an abstraction of those features of the real world that are considered relevant by the model builder. They therefore are only as good as the perception of their creators. Because of this, they are, and should be, only one part of the decision process. The acceptance of all or part of the model conclusions must be left to the experience of the responsible engineer. The engineer should make all efforts to validate or verify the models. Many different approaches and philosophies exist (e.g., how to verify models employed for long-term prediction for future-use levels).

There is also the question of overall model acceptance—model credibility in the eyes of the decision-makers, their staff, the general public, etc. The problem of model credibility needs to be dealt with in all stages of the planning process. Probably the best way is to have an open discussion about the model to be used both with the decision-makers and with the affected parties in the early stages of model selection.

According to the OTA study (U.S. OTA 1982), the lack of model credibility constitutes one of the most common reasons for the lack of use of models by decision-makers and other policy analysts.

There are many elements that contribute to the credibility level of an individual model (see Haimes 1981), including (i) the scope of the model, (ii) its structure, (iii) its modularity aspects, (iv) the number of objectives that it evaluates, (v) the acceptability and robustness of the assumptions made (both implicitly and explicitly), (vi) the quality of its data base, (vii) the sophistication of the optimization techniques used, (viii) the capability of the computers used, (ix) the quality of the interdisciplinary/multidisciplinary setup of the group that developed the model, (x) the level of model validation, (xi) the model's verification and testing, and (xii) the level of the risk and uncertainty elements.

In short, the needs and importance of model credibility in all aspects and phases of the planning process cannot be overemphasized.

Model calibration, as defined earlier, is a prerequisite for the use of mathematical models in systems analysis. The calibration of a model implies a commitment of time and financial resources. Therefore, models must be adjusted and/or adapted to the degree of accuracy required at the stage in question.

The use of more-sophisticated models may be of great help in calibrating the simplified and less expensive models that can be used
with higher efficiency for preliminary screening. A good and proper calibration of mathematical models may encourage decision-makers to use them as a helpful tool.

Models should not only be calibrated, they also must be independently verified. Often modelers tend to use all their information in the calibration phase and have no or little reserved information for the verification phase.

4.5 Interaction between analyst and decision-maker

The following three groups can be identified relevant to this stage of the planning process:

i) the planners

ii) the systems analyst, who provides technical support to the planners

iii) the policy-makers and public participants

Given that the planners have several objectives on their planning agenda (such as water supply, flood control, water quality, recreation), the planners may at the first interaction develop a first-cut plan or option of about four or five alternative plans. The analysts then use mathematical models that incorporate the various input-output relationships, objectives, and constraints to cast these alternative plans in a quantitative form. In particular, when multiobjective optimization models and methodologies are used, then Pareto optimal solutions and their corresponding trade-offs are also generated—all associated with the initial first-cut plans generated by the planners. The planners reevaluate their original four or five alternatives and modify them as appropriate, using the quantitative information generated by the analysts. The surrogate worth trade-off method, for example, can then be used here in a simulation mode. Following several iterations among the planners and the analyst(s), the four or five alternative plans are ready for evaluation by the public and/or policy analysts and decision-makers.

The analyst, when consulting with such decision-makers as politicians and senior bureaucrats, must be aware that they may try at this stage to exclude alternatives that compete with those that they favor. Decision-makers are commissioned, elected, appointed, or in some other way given the authority and responsibility to make decisions, and therefore the analyst should not play that role. Decision-makers can also identify political and institutional constraints that would exclude some alternatives. The main outlines must be presented to politicians, bureaucrats, and affected agencies early enough and thoroughly enough that they will not be taken by surprise and react, perhaps automatically, by completely rejecting the plan (which for them is the easiest way to react). Thorough discussions will help make them amenable to acceptance of the plan and to identifying themselves with it, so that they may ultimately become its advocates.

In screening alternatives, the planners should simultaneously represent four possibly conflicting interests, views and perspectives:

i) their agency (its mission and orientations)

ii) the public at large as manifested through public participation

iii) their professional judgment

iv) the overall goals and objectives of the original planning study

These four overlapping perspectives may not necessarily be compatible—they are often not. One of the planners' objectives should be the development and/or formulation of a final plan that can enhance the social well-being of the people in the region, can ultimately
be accepted by the public and other policy or decision-makers, and can also be implementable. In the screening process, this objective should guide the planners toward a compromise plan or solution that is viable and that has a reasonable chance of acceptance; otherwise, the planning effort would be only an exercise.

Inherent in multiobjective optimization methodologies is interaction with the decision-makers and the solicitation of their inputs and preferences. In the Maumee River Basin Case Study (see Case Study 4), for example, this interaction took place numerous times. The notion that there exists a single decision-maker in public projects is, of course, naive and unrealistic. In the Maumee Study, there was continuous and close interaction between the analysts and the decision-makers at various levels of the decision-making hierarchy. Each of these levels had its own influence and impact on the study outcome. Very often, the analysts were the decision-makers themselves. The hierarchy of decision makers consisted of the Planning Board members and their close associates, who in turn centralized the data and provided the needed technical information to the Planning Board. In addition, this hierarchy included the study manager and his staff, plus associates at the executive level of the Great Lakes Basin Commission, the Great Lakes Basin Commission itself, the Citizens' Advisory Committee, the Study Committee, the Steering Committee, the Water Resources Council, the public through various public hearings, and other agencies who were not represented in the above groups of decision-makers but who have influence in the region.

4.6 Compatibility with other plans and public participation

Even though cooperation with agencies during the planning process is essential, this will not necessarily lead to a coordinated output. There are several reasons for this:

1) Cooperation may not be considered important by all of the agencies
2) Too often a person without much responsibility or authority is sent to the meetings.
3) Not all meetings are attended, and reports are not considered seriously.
4) There may be basic disagreements among the agencies.

Nevertheless, it is important that a water plan not be negated by the activities of another agency's project, e.g., building a reservoir on the site of a major highway (or vice versa); a planned agricultural expansion being flooded by a reservoir; or having water quality improvement killed off by another country's diversion of flows. Thus, before the final plan is developed, it is important that appropriate officials (decision-makers) be involved--those who can agree to modifications and will ensure that they are done.

One should try to incorporate at least some of the compatibility conditions among planned activities as explicit constraints in the analysis--if they are indeed binding constraints. It is more efficient to consider the compatibility issues at the outset than just as a post-analysis matter.

In certain countries, public hearings and public participation are required by law prior to final approval of any major water resources project that involves public funds. These public hearings have a great advantage in that public concerns, objections, and views other than those of the interested agencies are heard, and often subsequent modifications are incorporated in these plans. There is a need to systematize this participation--to the extent possible--and integrate it with the entire planning and screening
process. The development (and design) of questionnaires that can articulate public preferences in a cogent way is also important. Also, the preliminary education of the public on the issues at stake and the preparatory steps for public hearings and evaluation of these alternative plans should be planned well in advance.

4.7 Procedures and techniques for screening alternatives

There are two principal options for dealing with the screening problem. In one, alternatives are screened via optimization carried out on the aggregated data and the simplified system representation. Application of linear programming as a screening device is a good example of the first option--no a priori identification of discrete alternatives is done. In the second option, a set of potential alternatives is somehow developed (often based simply on experts' recommendations), and they are then evaluated and ranked according to some criteria. In both options a single criterion or a multitude of criteria may be employed. Consequently, single-criterion or multiple-criteria techniques may be used. Appropriate procedures and techniques include the scalar and vector linear programming method, the SWT method, the Electre method, the score cards method, etc. Interactive man-machine procedures and decision support systems are becoming more and more used for screening purposes.

Screening of alternative plans is a continuous and iterative process. The techniques and procedures used for screening purposes are closely and largely dependent on:

i) the level of planning

ii) the stage in the planning process

iii) the iteration within the stage

iv) the availability of qualified and trained personnel who can make use of quantitative systemic approaches

v) the need for using such quantitative procedures

By means of optimization methods a large number of alternatives can be evaluated, but this can be achieved only at the expense of a detailed description of all alternatives. By contrast, a pure simulation model may allow for a very detailed description, but in this case only a few alternatives can be investigated. Depending on the project in question, the right system analysis tool should be selected. In a situation with a few clear, distinct alternatives, one should probably not implement an optimization model, but should rather choose a model by which the consequences of each alternative can be assessed in great detail. The opposite argument of course applies to the situation where a large number of more or less dependent decision variables must be considered. (This represents an "optimal" use of systems analysis technique.)

Any screening procedure at any stage of the planning phase requires that the following items be decided upon by consensus of the screening team:

a) a set of decision variables to be considered at the given stage (these become more specific and detailed as the planning process advances from one stage to the next)

b) a set of screening criteria to be employed

The screening team may vary from stage to stage.

A group technique (such as the nominal group technique) for screening alternatives at this initial level may be recommended, since politicians may argue for a long time without result if the arguments are not stated explicitly in writing.

Screening and generation may often be considered as a complex, repeated activity; i.e., after each screening the reduced number of alternatives is increased again by
allowing for more detail in the description of alternatives.

In summary, screening techniques may range anywhere between "rule of thumb" and "formal optimization," depending on the type of problem and the level of screening at which ranking procedures are used.

4.8 Use of hierarchical analysis in plan formulation and screening alternatives

A necessary condition for the successful use of systems methodologies for water resources planning is the ability to develop a (mathematical) model that is responsive to (and accounts for) the various objectives, constraints, and input-output casual relationships of the system that is being modeled. Only if this condition is met will the results of the model be meaningful and implementable.

The hierarchical approach possesses many important attributes for both modeling and optimization. The hierarchical approach is, in the first place, a philosophy and not a rigid methodology. This philosophy recognizes that water resources systems have most of the following characteristics (Haimes 1977):

i) multiple noncommensurable objectives as well as multiple decision-makers

ii) a large number of variables and parameters

iii) a large number of coupled components (subsystems)

iv) input-output causal relationships that are nonlinear (often a combination of continuous, discrete, and 0-1 decisions); dynamic (time dependent); non-deterministic, with high elements of risk and uncertainties; and having distributed parameters

v) variability of portions of the system (problem), which gets in the way of quantitative modeling

Such complexity suggests that simple systems methodologies are likely to fall short of successfully modeling and optimizing water resources systems with the above characteristics.

The concept of the hierarchical approach is based on the decomposition of large-scale and complex systems and the subsequent modeling of the system into "independent" subsystems. This decentralized approach, by utilizing the concepts of levels, strata, and layers, enables the systems analyst to assess and comprehend the behavior of the subsystems at a lower level and to transmit the information obtained to fewer subsystems at a higher level.

In applying the hierarchical approach to the modeling and optimization of water resources systems, combinations of several hierarchical structures are available to the analyst. These combinations are based on four major descriptions (decompositions), namely:

(1) temporal

(2) physical-hydrological

(3) political-geographical

(4) goal-oriented or functional

(1) Temporal description

A planning time horizon for
water supply projects often spans 30-50 years. Into this long-term planning is usually imbedded an intermediate term of 10-15 years, often referred to as planning-for-operation, followed by a short term of 2-5 years. Clearly, the short-, intermediate-, and long-term plans have to be compatible with each other and thus coordinated, since they relate to the same system. To illustrate, planning horizons of water resources for crop and related land use can be of the order of 1-2 years. However, when a crop has been selected and the water for its seasonal growth has been allocated, horizons of decisions with respect to the periodic irrigation within the season are of the order of weeks or days.

(2) Physical-hydrological description

A river basin is, by definition, a hydrologically self-contained region, separated from adjacent basins by ridges or other topographical dividers. Often a water resources management system covers a region consisting of a complex of several river basins. Thus, a region can be divided into several subregions, further divided into several river basins, and further divided into several subbasins.

(3) Political-geographical description

Regional water resources systems often come under a variety of geographically defined governing agencies--city, county, and state, for instance. Modeling for water resources planning and management may consider a political-geographical description as a criterion for decomposing the regional area into subregions.

(4) Goal-oriented or functional description

Most water resources systems have been analyzed with respect to their economic and functional goals. Various models following this pattern are available in the literature, such as demand and supply models and models for hydroelectric power generation, irrigation, industrial and municipal use, recreation, etc.

4.9 Use of multiobjective analysis

A recent trend in systems analysis has been to use models that have more than one objective function. This is especially important in the planning of river basins, where there tend to be several conflicting and noncommensurable objectives. For example, one may want to maximize both economic efficiency, which is measured in monetary units, and environmental quality, which is measured in units of pollutant concentration. Traditionally, only one objective (economic efficiency) has been considered, with the other objectives being included either as constraints or as being somehow commensurate with the primary objective. However, society is placing an increasing importance on nonpecuniary objectives that are difficult to quantify monetarily.

Adopting a multiobjective analysis philosophy in this stage of the planning process (as well as in the other stages) adds to the systemic and quantitative setup. Cost-benefit analysis has traditionally dominated both Stage 3 and Stage 4. It can be easily demonstrated that cost-benefit analysis is a special case (a simplified case) of multiobjective analysis; it is the case in which all objectives have been commensurated and augmented in terms of benefits and costs.

Fundamental to multiobjective analysis is the Pareto optimum, which is also known as the noninferior solution. Qualitatively, a noninferior solution of a multiobjective problem is one where any improvement of one objective function can be achieved only at the expense of degrading another.
Mathematical modeling and systems engineering should not be a substitute for, but rather tools of, the decision-making process. They can be very valuable in generating possible outcomes under certain conditions and assumptions. They are capable of generating alternative policies and plans that are "optimal" under specific assumptions and criteria. In multiobjective planning, where the concept of optimality is expanded into Pareto optimality, the generation of the various model Pareto optimal plans can be invaluable in identifying specific characteristics and attributes of a basin's planning subarea as well as in quantifying the complex interrelationships among the many components in the planning process. Once the limitations of the mathematical models under consideration are identified and quantified, they can be used very effectively as simulation models to answer "what if" type questions. The experience gained using the surrogate worth trade-off (SWT) method reinforces the need for integrating mathematical models and simulation models to improve the efficacy of the planning process.

The application of the SWT method to various problems with multiobjective functions can be extended to the minimization of risk, sensitivity, irreversibility, and uncertainty associated with mathematical models jointly with the minimization of the model's objective function, in a multiobjective framework. The Pareto optimal solutions and the associated trade-off values help the decision-makers select an acceptable level of assurance and the corresponding cost. In other words, decision-makers can make known their preferences with respect to the level of assurance against uncertainties in the model's prediction at the expense of a degradation (reduction) in the model's optimal solution.

The subject of multiobjective analysis should be explicitly discussed at each step of the planning process because of its central role in water resource planning. Most, if not all, water resources systems are characterized by multiple objectives, multiple decision-makers, and multiple constituencies. In formulating and screening alternative plans, these multiple objectives, which are often noncommensurable and may be in conflict and in competition, must be given explicit and quantitative consideration (to the extent possible). For example, increasing agricultural production commonly leads to a higher level of sheet erosion and sedimentation; or the optimal use of reservoirs for flood control purposes may be achieved at the expense of reducing hydro-power generation (as applicable), etc.

Multiobjective analysis in this context should be viewed not only as a methodological approach but also as a philosophy. Trade-offs are an inherent part of negotiation, of reaching consensus, and of compromise solutions. Thus, the use of multiobjective and trade-off analysis in the development of final plan results can be a natural step in this phase. This is particularly true when the analysts, planners, and decision-makers are cognizant of the efficacy, attributes, and limitations of multiobjective analysis.

Numerous methodologies for multiobjective optimization (analysis) have been developed in the last decade—many of them in conjunction with water resource planning and management. Several books are available today on the use of multiple objectives in water resource planning and management.

The role of multiobjective analysis is particularly critical in the addressing nonstructural plans, in which the cost, benefits, and risks cannot be easily quantified in monetary terms as they can in more structured plans. Furthermore, as environmental and other socioeconomic aspects dominate and influence policy decisions, the importance and needs of multiobjective analysis become more
and more critical and evident. An example of the complexly interrelated objectives that must be dealt with is found in the Maumee Planning Study (see Case Study 4), in which the following six objectives were included in the mathematical modeling and comprehensive analysis:

1) enhancement of water quality, focusing on point-source pollution

2) reduction of erosion, sedimentation, and phosphorus from nonpoint sources

3) enhancement of recreational opportunities

4) protection of wildlife habitat

5) reduction of flood damage

6) protection of agricultural land

For most water resources systems (and many other systems as well), decisions are not made by a single individual but rather by groups of individuals. These may be legislative bodies, the board of directors of a water district, a state official, etc. In every case, each member of the group has a personal view of the significance, importance, and relative value of the various objectives being considered. Furthermore, each decision-maker may have a constituency to whom he or she is responsible. This means that the decision-maker must integrate the relative influence and views of the segments of this constituency into the evaluation of the merits of the alternatives. The critical influence of these decision-makers and stakeholders must be recognized throughout the planning process.

In this handbook, a distinction should be made between two aspects—(i) the needs, importance, and efficacy of multiobjective analysis and (ii) the methodologies and techniques of multiobjective analysis. Obviously our attention should focus on the former, and not on the latter.

A recent development of multiobjective analysis is its use in a man-machine interactive mode, through decision support systems (DSSs). In Israel, for example, a DSS has been developed for project screening. In this DSS, all projects are subjected to examination in terms of 38 criteria that have an overall goal of assessing a minimum-damage function for delaying a project's construction. Successful experimentations with gaming simulation have been realized, in which part of the simulation of a human natural-resources engineering-hardware system is executed "automatically" by computer, while the human part is carried out by people playing roles. It is sometimes possible to get the real-life decision-makers to play their own roles. In this era of increasing availability of computers, a DSS might be a very promising concept that could help decision-makers to more clearly see the consequences of their subjective preferences.

To sum up, real-world decision-making processes are always associated with multiobjective problems. The most important tasks of analysts who cope with the conduct of multiobjective analysis is to make the decision-makers aware that they are actually doing that kind of analysis, implicitly, in their minds. Thus, it is important to put some order in their way of thinking, because a mathematical model can never be developed to replace the decision-maker's way of handling multiobjective optimization problems.

4.10 References


5. Development of final study results

In Stage 4, the planning team, following extensive discussion, negotiation, and public hearings, selects a plan and recommends its adoption to higher-level authority. These recommendations are made only after the completion of Stage 3, during which the team (i) has successfully conducted a feasibility study to evaluate the financial, political, legal-regulatory, organizational, and personnel ramifications of the proposed plan and its impacts, (ii) has identified, quantified, and evaluated all pertinent elements of risk and uncertainty associated with the plan as part of the multiobjective trade-off evaluation and optimization activity, and (iii) has developed operational rules within a planning-for-operation study for all pertinent project(s) that have been developed as part of the overall plan.

5.1 The relationship between Stages 3 and 4

As mentioned previously, there exists a certain overlap between Stages 3 and 4 of the planning process. In a real sense, there is a logical continuum between the screening of project alternatives and the development of final study results.

More specifically, the process of planning, designing, and operating water resources projects lends itself to a hierarchical structure of subsystems as well as decisions. It is often common that higher-order and more global decisions dictate and influence lower-level and more local or parochial decisions, and vice-versa. Yet, at Stage 3 of the planning process, an attempt is made at executing high-level planning without a detailed design or planning-for-operation analysis. Consequently, the preliminary screenings at Stage 3 are made without the detailed analyses that are commonly conducted at Stage 4. However, from a practical viewpoint and given the limited available time and resources, the proposed sequence of Stages 3 and 4 is recommended here.

The planner should also keep in mind that Stage 4 may be directly coupled with Stage 2 in terms of data development and improvement. Furthermore, at Stage 4 the planners may find it necessary to request a project design (Stage 5) in order to generate more-accurate cost functions of candidate structures or other measures that are being contemplated. Note that in certain studies, only one plan may be selected, and a detailed project configuration would be appropriate for that plan alone. However, under different circumstances, more than one plan may be selected and subsequently more than one project configuration would be in order.

Stage 3 amounts to a preliminary screening, while Stage 4 is intended to lead the project very close to its final recommended configuration (or the equivalent of this at another level of planning). Because of this, Stage 4 is likely to require the allocation of more resources and the use of more sophisticated techniques, and the entire process is likely to be more thoroughly executed. Results obtained in Stage 4 may suggest the need for a repetition of some portions of Stage 3 (an iterative loop), with perhaps the generation of one or more additional alternatives.

During Stage 4, the project is analyzed in detail, including the generation of one or more suitable integrated models, which will require the following steps:
a. quantitative definition of all variables and terms

b. quantification (to the extent possible) of all final
   - objectives
   - constraints
   - input-output relationships
   - measures--structural and nonstructural

c. identification and evaluation of available existing models and submodels that might be candidates for use in Stage 4 of the planning process

d. evaluation of the data base needed for step c above needed

e. construction of new models and submodels

f. integration of newly developed models and submodels with existing models, as appropriate

g. generation of needed projections

h. model testing, calibration, and validation, as appropriate

The final result of this stage presumably leads to an "optimal" plan, better known as the most preferred or the least compromised plan. The planning and policy option developed through the use of models and their associated trade-offs and impacts are discussed in detail at this stage. This is done with the participation of all concerned decision-makers, stake-holders, constituencies, and agencies.

5.2 Input to and output from Stage 4

The essential interactions that take place between Stage 4 and the other stages of the planning process will be summarized in this section:

A) Input to Stage 4

Stage 4 requires at least the following inputs:

* the screening results from Stage 3, where a large number of poorly defined alternative plans were considered. (The term poorly defined refers to the fuzziness of project dimensions, uncertainty about the time of commissioning, and vagueness concerning other operational properties).

* additional endogenous and exogenous system data, building on the data that were just sufficiently detailed and accurate to permit the screening at Stage 3.

B) Output from Stage 4 needed for feasibility study

A project feasibility study is a process that subjects the project and its various components to a set of pre-selected qualification, standards, and criteria. The project and its components must meet these qualifications in order to be designated as "feasible." Such standards and criteria generally include technical economic, legal-regulatory, and environmental aspects. Project feasibility does not include, in general, financial, organizational, or institutional feasibility. Rather, the feasibility study provides the basis upon which financial arrangements (e.g., funding sources, cost-sharing, bonds, etc), organizational arrangements (e.g., hiring of personnel, administrative structure, levels of responsibilities, etc.), or institutional arrangements (e.g., agency responsibility, interagency coordination, etc.) can be established in the future. The feasibility study should also include:

* identification of a selected project--the best alternative plan--and setting the main project parameters to justify and support the project.

* generation of a project
feasibility statement. The "statement of feasibility--including technical, economic, and environmental feasibility--often does not include financial feasibility recommendations with regard to organizational and institutional aspects of the project.

C) Output from Stage 4 needed for project study, etc.

The output from Stage 4 makes possible the final design of the project. It includes the specification of all parameters needed for the design, such as the quantity of water to be released, the demand as function of time, and the location and sizes of reservoirs, canals, conduits, and the like. The output also provides information on operational rules and usually identifies and assesses all the large-scale impacts resulting from the project. It does not entail a detailed design of the required structures, although the cost estimates and their dimensions should be known roughly. Therefore the output includes:

* final specification of the main project parameters and properties
* final estimate of project commissioning state
* final estimate of project impacts (costs, benefits, risks, trade-offs, etc.) including cash flow and return estimates
* recommendation for project

5.3 Sources, quality and categories of Stage 4 data needs

Although Stage 2 of the planning process--data collection and processing--has been identified as the stage during which data activities are emphasized, the planners continually discover during later stages that additional information is needed and some responsive action must be taken. At one extreme, a data collection process might be initiated at this stage. At the other extreme, an artificial or synthetic data base might be generated from other sources having similar characteristics (regional, structural, socioeconomic, etc.).

In general, data are needed in more detail in Stage 4 than in Stage 3. In addition, data collected in Stage 2 and not used in Stage 3 often become critically important in Stage 4. This is particularly true for determination of a specific site selection or in the evaluation of secondary and tertiary socioeconomic effects that are implied by a specific project selection.

At Stage 4 of the planning process, all information sources--agencies at all levels, civic groups, and private sources--must be used in order to have access to the available data. Processing data from different data banks through the use of computer facilities is becoming the rule rather than the exception. Most importantly, assumptions about conjectural data must be well explained, justified, and documented.

The most critical data needs at this stage concern the financial, political, legal-regulatory, organizational, and personnel aspects.

(a) Financial

When several levels of government are involved, knowledge of the availability of funds from each level of government is needed. In the U.S., for example, federal, state, local, and often regional fundings may be required or are available. Furthermore, information on approaches to
cost-sharing and revenue-sharing and their impact on the plan could be essential to the ultimate success of the plan implementation. Often, there are plans for one level of government (e.g., state) that are mandated by another level of government (e.g., federal). "Who should pay for what?" is a challenging question, and information on related and relevant precedence might be very helpful.

(b) Political

Although knowledge about a region's or basin's hydrology, geomorphology, socioeconomic development, and a myriad of other seemingly imperative factors dominate the process of water resources planning, it is often political knowledge—about the political climate, the political will to support a plan, and the political coalitions that can be formed—that is essential to the success or failure of a plan. Political will is essential for the support of a plan, and knowing how to marshal such political will should be part of the agenda of the planning team. Because a select group can block a plan, a much larger consensus among the true stakeholders, influential groups, and affected parties should be sought to realize the success of a plan. Understanding the political environment and appreciating the positive effect of the consensus-building process within the political system should be high on the planning agenda.

(c) Legal-Regulatory

Knowledge of the various legal and regulatory systems that affect and are affected by a plan is needed. Consider the multiregulatory frameworks associated with a local government with its various municipalities, counties, districts, and regional agencies. The planners, in their selection of the final plan, must be cognizant of the mutual implications and impacts between these multiregulatory frameworks and the selected plan as such. For example, differences in zoning codes among adjacent districts may prove to be a major impediment to an important component of the plan.

(d) Organizational

The various levels of government—local, state, regional, and federal—need to develop the appropriate organization and administrative structure to exercise the authority for the management of the water resources project provided by the legal-regulatory framework. The planners should understand that the implementation of their plan requires the development of such an appropriate organizational and administrative structure. Thus, information collected on the organizational aspect at this stage of the planning process can prove to be extremely beneficial to all concerned parties. In particular, when the planners consider the hierarchical decision-making structure within which the plan is developed, their knowledge about the centralized and/or decentralized responsibilities among the various parties can only be helpful to the planning process.

(e) Personnel

Comprehensive planning for a river basin or other water resource necessitates comprehensive planning for qualified and trained personnel. Past experience shows that one way to ensure a more harmonious implementation of the plan is to make early preparation for qualified staff to fill the variety of needed positions, both
scientific-technical (e.g., hydrologists, engineers, soil-scientists, modelers and computer analysts, agronomists, etc.) and administrative-legal (e.g., managers, lawyers, economists, planners, clerks, etc.). The fact that it takes considerable effort to prepare an adequate staff requires that information on the availability of such personnel be sought by the planners at this stage of the planning process. A carefully planned training program must be proposed as part of the total package.

5.4 The role of modeling, simulation and optimization

Simple and aggregate models are used in Stage 3. Thus, in trading-off between accuracy on the one hand and computational feasibility on the other, the planner often tips the balance toward the latter in order to generate fast, reasonable, and plausible results. In Stage 4, however, the balance should be moved in favor of a great accuracy and more detail. Furthermore, Stage 4 necessitates the use of all available systematic procedures of systems analysis in order to refine, augment, and adopt the models employed. Some specific suggestions about how to do these follow:

To refine: Modify coefficients and/or delete constraints without changing the basic structure.

To augment: Use other models. For example, use simulation to test and verify the results of optimization. The other models may now include aspects not previously considered explicitly, such as a detailed modeling of the operation, which appeared in a simplified form earlier.

To adopt: Use models developed by others, or compare results with those generated by others.

An important requisite for the viable use of models in the planning process is the perception (by the planners and the public) of their credibility (see also Section 4.4). The assurance that model results are reliable is imperative in Stage 4. If the models suffers from fuzziness in Stage 3, this will not as adversely affect the soundness of the final project selection as if this occurs in Stage 4. Most importantly, the entire study can lose the participatory support of the concerned agencies and the public if the models and procedures used are perceived as lacking in credibility and scientific grounding.

An integrated use of simulation and optimization has proven to be most effective in many studies and has become the preferred modus operandi of systems analysis practitioners. Depending on the specific needs of a model, optimization and simulation are related in one of the following ways:

i) Optimization may be followed by simulation.

ii) Optimization may be included in simulation.

iii) Simulation may be used for model quantification (primarily the quantification of objective functions) and followed by optimization.

iv) Simulation may be used as a search technique for identifying an optimum.

The use of simulation as a search technique often occurs in complex problems with a large number of alternatives and with limited available computing facilities. The exclusive use of optimization (in the generation of operational rules) often requires that the stochasticity is dealt with in an approximate way. This problem may be alleviated by the use of stochastic hydrology, i.e.,
5.5 Risk and uncertainty

The fact that water resources systems—public and private—are planned, designed, constructed, operated, and modified under conditions of risk and uncertainty necessitates that the numerous elements of risk and uncertainty be considered throughout the planning process, and particularly during the development of final study results.

Risk is associated with the possibility of suffering harm, loss, danger, failure, or other adverse effects as a result of taking an action or a sequence of actions. It consists of the following two basic elements: (i) magnitude of the risk and (ii) the likelihood it will cause harm or adverse effects. To describe a risky situation, we must therefore adequately describe these two basic elements.

The U.S. Water Resources Council (1980) identifies two major sources of risk and uncertainty:

1. Risk and uncertainty arise from measurement errors and from the underlying variability of complex natural, social, and economic situations. If the analyst is uncertain because the data are imperfect or the analytical tools crude, the plan is subject to measurement errors, and these obviously can be minimized by improved data and refined analytic techniques.

2. Some future demographic, economic, hydrologic, and meteorological events are essentially unpredictable because they are subject to random influences. The analyst must decide whether the randomness can be described by some probability distribution. If there is a historical data base that is applicable to the future, distributions can be described or approximated by objective techniques. If no such historical data base exists, the probability distribution of random future events can be described subjectively, based upon the best available insight and judgment.

It is often useful to distinguish among the following three risk-related situations that reflect the different levels of information available for risk assessment and management:

- **Risk situations**—situations in which the potential outcome can be described by reasonably well-known probability distributions.

- **Imprecision situations**—situations having potential outcomes that cannot be described in terms of objectively known probability distributions, but which can be estimated by subjective probabilities.

- **Uncertainty situations**—situations in which potential outcomes cannot be described in terms of objectively known probability distributions.

These are not merely abstract definitions; rather, each situation requires the use of different approaches and tools for quantification or evaluation purposes.

The total risk issue is addressed through the process of risk assessment and management. To perform the complete process of risk assessment for a particular problem, the following tasks need to be carried out (Haimes 1981):

1) Risk identification, which involves identification of the nature, types, and sources of risks and uncertainties. In general, the major types of risks are financial, health-related, environmental,
technical, and technological (e.g., performance and supportability). The end product of this task is a complete description of risky events and elements of major concern along with their causative factors and mechanisms.

2) Risk quantification, which entails formulating appropriate measures of risk and estimating the likelihood (probability) of occurrence of all consequences associated with risky events as well as the magnitude of such consequences.

3) Risk evaluation, which includes selection of evaluation procedures (e.g. optimizing expected value, trade-off analysis) and analysis of various possible impacts of risky events.

4) Risk acceptance and aversion, which require decision-making regarding both an acceptable level of risk and its equitable distribution. This phase of risk assessment also involves the development of risk control (i.e., measures to reduce or prevent risk).

5) Risk management, which involves the formulation of policies, the development of risk-control options (i.e. methods to reduce or prevent risk), and execution of such policy options.

The last two stages of the risk-assessment process—risk acceptance and aversion and risk management—overlap to a large extent and require the subjective judgment of the appropriate decision-makers in trading-off the noncommensurate beneficial and adverse consequences resulting from the ultimate "acceptable risk" decision. The existence of these fundamental trade-offs among conflicting and noncommensurate multiple objectives and attributes demands the consideration of risk management as an integral part of the overall decision-making process—which is the imperative premise assumed here.

It is instructive to articulate, at this stage, the difference between the process of risk assessment and the methodologies of risk assessment.

The process of risk assessment is the aggregation of interactions with decision-makers in the application of risk assessment approaches. (These interactions involve trade-off analysis and the exercise of value judgments.)

The methodologies of risk assessment are the techniques utilized in a scientific approach to estimating probabilities and performing risk assessment (excluding the application of value judgments)—an integral part of the process.

It is also noteworthy that the risk assessment process—the setting of value judgments and quantification—is critically important, because it facilitates the educational process of the analysts and decision-makers and their understanding of the methodologies. In turn, the methodologies serve as important stimuli for decision (in addition to their contribution to the quantification of information and its transformation into intelligence), even if the methodologies themselves are not very good. Clearly, methodologies are a necessary condition for a credible and viable risk assessment process, but are not, by any means, sufficient.

This process can help to identify and articulate the issues upon which there is agreement among decision-makers, and also those for which there is no agreement. The process also helps to make the implicit explicit. This outcome, however, may embarrass decision-makers under certain circumstances.
The ultimate efficacy of risk assessment in water resources planning and management can be measured by the assistance it provides planners and the decision-makers involved in planning and/or management. It renders this assistance in the following ways:

(a) It identifies the sources of risk and uncertainty associated with exogenous variables and events derived from demographic, economic, hydrologic, meteorological, environmental, institutional, and political factors.

(b) It quantifies the input-output relationships with respect to the randomness of these exogenous variables and events to the degree possible and feasible, given the constraints on data and information.

(c) It quantifies, to the degree possible and feasible, the potential or probable impacts that risk and uncertainty and their associated trade-offs will have on alternative policy decisions.

(d) It facilitates the decision-making process by enabling decision-makers to make the utmost scientific use of information about risk and uncertainty related to the trade-off and decision analysis of human factors.

5.6 Sensitivity analysis

Sensitivity analysis is an integral and important part of Stage 4 of the water resources process because of the inherent randomness of hydrologic and socioeconomic events. In the revised Principles and Standards for Water and Related Land Resources Planning, Level-C (Federal Register 1980), the U.S. Water Resources Council states: "The planner's primary role in dealing with risk and uncertainty is to identify the areas of sensitivity and describe them clearly so that decisions can be made with knowledge of the degree of reliability of available information." The ideas and methodology advocated in this section are both in congruence with and in support of the above statement. While there is near unanimity among water planners regarding the imperativeness of sensitivity analysis, the ways and means of conducting sensitivity analysis and integrating it into the overall study or plan are still debatable. In particular, the trend has been to use sensitivity analysis as a post-study and extrinsic evaluation (of the study), rather than as a genuine component of the study in terms of trade-off analysis of the risks, cost, and benefits—as proposed here.

The use of combined uncertainty and sensitivity analysis in water resources planning has gained some attention in the literature in recent years. The uncertainty sensitivity index method (USIM) developed by Haimes and Hall (1977) is such an example. It can be shown that a business-as-usual policy (ignoring uncertainty and sensitivity analysis) can be too costly in terms of deviation from achieving the original model objectives. The USIM assesses, in a multiobjective framework, the trade-offs between the cost of added assurance and the threats posed by uncertainty.

The definition of risk in the sense of an objective to be minimized appears to be simple, but this is deceptive since the minimization of risk is in fact extremely complex. At question is usually a long list of undesirable outcomes and combinations of outcomes, each with a non-negligible probability of occurring.

While in some cases a specific quantitative risk index can be defined and used as an objective, more often there will be an excessive number of such indices. In such cases, it is possible that certain risk-related characteristics of the system can be identified, quantified, and used to serve as a
single measure of many of those individual risk objectives. Among these characteristics, sensitivity—which relates changes in the system's performance index (what we have been calling output) to possible variations in the decision variables, constraint levels, and uncontrolled parameters (model coefficients)—is particularly important.

5.7 Uncertainties associated with goals and objectives

Goals and objectives—once adopted by the planning team—become the dominant force that drives the planning process. Goals are positive attributes or characteristics strived for by individuals or society. Goals of individuals and society are an unbounded set; i.e., any stated goal is included within at least one more-encompassing goal, and there is a set of more narrowly defined goals within it (TECHOM 1974). Two major sources of uncertainty related to planning goals and objectives should be identified and addressed at this stage of the planning process. These are (i) perceptions of long-term societal goals and objectives and (ii) perceptions of the long-term availability of technological and nontechnological measures (means) with which the planning goals and objectives can be achieved.

It is worth noting that societal goals and objectives are intrinsically hierarchical—a fact that magnifies what the uncertainty associated with each subgoal and subobjective contributes to the uncertainty of the overall societal goals and objectives. Consider, for example, that enhancing economic opportunity is an important societal goal in the planning process (TECHOM 1974). The following many constitute a set of subobjectives of this goal:

(i) enhancing present living standards

(ii) enhancing future living standards

(iii) enhancing equality of economic opportunity.

Furthermore, sub-subobjectives for (i) may be

(i) increasing income

(ii) increasing consumption of goods and services

(iii) increasing leisure time

(iv) increasing stability of the economy

A further look at the hierarchy of sub-subobjectives for (iv) above may be

(i) increasing the growth rate of per capita income

(ii) decreasing the rate of inflation nationwide

(iii) reducing present unemployment

(iv) reducing present business failure,

and so on.

The point is that there are myriad sources of errors and uncertainties in the data base, the modelling assumptions, the models themselves, and human perceptions; moreover, these errors and uncertainties are associated with all levels of goals and objectives, which means that the planning team must make a concerted effort to account for them, especially during the stage of final plan selection. This accountability can be achieved through the use of quantitative-empirical methods or heuristic-normative approaches, or through an appropriate combination of both.

The same argument applies to uncertainties associated with the perception of the availability of long-term technological and nontechnological means of achieving the planning goals and objectives. This is particularly true for the
assessment of future technology and its cost, reliability, and acceptability. Any one of numerous examples, from DDT to asbestos to solid-waste disposal, can serve as a case in point.

Thus, the planning team should assess and evaluate the uncertainties associated with the goals upon which the selected plan(s) are grounded and with the ways and means (measures) of realizing these goals.

5.8 Impact analysis and policy analysis

An important goal of systems analysis is the reduction of unintended or undeserved consequences. Impact analysis, which is the part of policy analysis concerned with these issues, contributes to the achievement of this goal by the identification, evaluation, and alleviation of projected adverse effects.

While the planning alternatives in Stage 3 are screened on the basis of aggregate data and simplified system representation, the level of accuracy at that stage does not allow the consideration of all primary and secondary impacts in sufficient detail.

However, in Stage 4, the environmental, economic, and social impacts of a few selected alternatives are considered in more depth. Several systems analysis methodologies are available for impact and policy analyses, including the Leopold matrix and the multiobjective multistage impact analysis method (Gomide and Haimes 1984). Generally, impact and policy analyses can be carried out on two separate, albeit somehow overlapping, levels. One level of analysis is endogenous--pertinent to the water resources system models used in the planning. This level includes the sensitivity and uncertainties associated with the modelers' assumptions about the models and their structure, topology, parameters, data bases, optimization techniques, etc. To some extent, endogenous impacts are controllable by the modeler. The other level of analysis is exogenous to the models and concentrates on the influence of various policy options on the overall socioeconomic environment and how it is likely to react to this influence. A water project can have an impact on many aspects of society--education, population distribution, transportation, health safety, and economic dislocation. From a welfare economic perspective, a large investment in any sector, including the water sector, precludes funds and resources from going to other sectors in any given economy. International funding agencies are particularly eager to evaluate such aspects before they fund large-scale water projects. The impact analysis component is particularly important in Stage 4 of the planning process, where every plan or policy option should be accompanied by policy analysis--so that all future and project consequences (both favorable and unfavorable) should be identified, assessed, quantified (to the extent possible), and integrated within the decision-making process.

Impact analysis and policy analysis should be particularly focused on the risk and uncertainty associated with water resources planning and decision making. The planning activity, by definition, represents futuristic aspects, where elements of risk and uncertainty dominate socioeconomic, demographic, environmental, and institutional projections.

5.9 Model(s) as part of the study product

Two categories of models can be identified as a by-product of the study:

(a) models used for the planning process, which may be models developed specifically for the study or adopted from other water resources planning studies
(b) models for the operation of the system to be implemented

These models may be developed as planning-for-operation models during the planning or design process. Each of the two categories of models should be well adapted to existing computer facilities and must be presented to the user in a form suitable for proper and efficient utilization.

If one accepts the premise that planning is a continuous, never-ending process for which appropriate institutional conditions must be created, then the importance of models as a part of the study product cannot be over emphasized. This, in particular, refers to large-scale, long-term planning studies. In all cases, the second type of models mentioned above is important. Making the model part of the product means that the customer will be in a position to continue the work. In addition, this transfer of the model also entails transfer of ideas, communication with the clients at a very detailed level, closing credibility gaps, etc.

The subject of models as part of the study product brings to focus the important issues of technology transfer, model maintenance, and clearinghouses for models; these issues were addressed in detail in the 1982 study by the Office of Technology Assessment, U.S. Congress (U.S. OTA 1982).

In large and complicated studies, models are often considered as part of the project to be delivered to the customer, including an operable program of the model that is suitable to the customer's computer facilities. These models may prove to be most valuable to the customer for future use for reevaluation of new data or for modifications in the original project required by changes in exogenous variables or demand parameters. The model and its computer program should be made available to the customer in what is known as user-friendly packages and should be well documented, with all steps made transparent through flow charts, text statements, examples, and figures.

The training of personnel who can operate and use these models—an integral part of a project's product—is often essential. Sadly, this often constitutes one of the weakest links in the planning process. It should be the practice in development aid projects to leave all the software that has been used with the receiving counterpart agency, and in some projects even the computers will need to be supplied. Accordingly, the training of personnel plays an ever-increasing importance. This is particularly critical (and almost imperative) in developing countries.

5.10 Planning for operation

Planning for operation, which generally leads to the generation of operational rules for the project, is perhaps one of the most important technical steps in the planning process. It is also the most intensive systems analysis step, where the synergism resulting from the integration of simulation and optimization is most evident in its potency. Although the operational rules generated in the planning-for-operation step are developed for the entire planning horizon, they are not expected to be followed to the letter in actuality. Indeed, these operational rules are often modified once the project is completed and the real-world operation commences. However, they do serve the following important objectives in the planning process:

(a) Provide an analytical mechanism with which to develop design criteria and, thus, optimize the project design.

(b) Enable the planner-designer to better understand the couplings among the various subsystems (reservoirs, rivers, groundwater systems, etc.) and, consequently, to account for the
systems constraints and systems attributes.

(c) Enable the agency, or agencies, responsible for operating the project to initiate contractual agreements with, for example, electric power utilities or water supply districts. These contracts can be very tight in their degrees of freedom and, therefore, a well-developed set of operational rules can become an essential ingredient in ensuring the overall success of the project.

(d) May lead to discovery of major gaps in data needs. In this case, a new data collection process can be started much earlier than otherwise.

(e) May help to uncover early signs of conflicts with other agencies and/or water resources operating entities. In this case, a process of negotiation may be initiated and/or some of the project design may be altered to accommodate these newly discovered institutional or organizational constraints.

(f) Provide an indispensable training medium for those who are commissioned to operate and manage the project when it is completed.

(g) Assist in the development of a cost-sharing formula for the project (as appropriate).

These and other objectives associated with the operational rules dictate that the planning team adhere to a well-conducted planning-for-operation step in the planning process.

5.11 Modes of presenting the plan to the decision-makers

A good system study loses its value when the system analyst is not able to convince the decision-maker(s) of the study usefulness. Therefore, the decision-maker(s) should be involved as much as possible in the process of model building, model optimization, and model presentation. The studies that have found the best acceptance and that are actually implemented are mostly studies in which the decision-makers have been so closely involved that they identify with them.

However, in many studies such an involvement is not possible, and the analyst has to convince the decision-makers of the efficacy of the finished product. Most important is that the results of the study must be presented in a clear and convincing manner, with as little technical jargon as possible. The text should be accompanied with meaningful and self-explanatory figures. Only figures that directly relate to the results should be shown in the main text, with all other material relegated to appendices or to special annexes.

Interaction with the decision-maker(s) throughout the entire planning process should be emphasized—if there is insufficient interaction in Stage 1, even the best visual will not help in Stage 4.

Most studies and reports will be reviewed by people representing a wide spectrum of backgrounds and interests. A technique that can sufficiently cover such a range is to offer three main segments, each written at a somewhat different level:

(i) A summary devoid of technical jargon can be written that will be suitable for politicians, senior bureaucrats, and journalists.

(ii) The main text can be directed toward the professionals, who may have to advise but who are not necessarily directly involved in the work.

(iii) Technical appendices can be added that are aimed at those who either are already involved in the project or who may become involved at a later stage.
For this latter category of technical experts, the material in the appendices must be presented in sufficient detail to enable them to check, verify, contradict if appropriate, or change parameter values in further work. All these modes contribute toward the decision-makers' understanding of the results.

There are, of course, different levels of decisions that must be made--technical, political, etc. During the technical development of the study, it would be advantageous to have discussions and share the progress with the involved decision-maker. In most cases, the decision-maker will be interested in the extent to which the planner has considered various options. Another aspect of the mode of presentation and communication with the decision-maker involves the presentation of trade-offs in a multiobjective framework. While it is possible (and is just as easy) to generate trade-offs between, say, recreational activities in visitor/day units and flood damage in areas of flooded land, communication with the decision-maker is generally much easier and more meaningful if these trade-offs are presented in terms, say, of $/visitor-day and $/acre (of flooded land). In such a case, the cost function measured in monetary units will be used as the primary objective in the surrogate worth trade-off (SWT) method of the -constraint formulation.

Furthermore, communicating absolute values of levels of objectives to the decision-makers (such as cost, flood damage, recreation, etc.) is often not as meaningful as if these results are communicated in terms of a percentage of a base level (say, present conditions). Then, the percentage of improvement (or degradation) can be juxtaposed with the absolute levels, and the decision-maker will be in a position to judge for himself the achievements (or lack of them).

Finally, the use of computer graphics through an interactive man-machine mode adds a new dimension to the use of systems analysis in water resources planning (see, for example, Loucks, Kindler, and Fedra, 1985).

5.12 References

Federal Register. September 23, 1980, 45(190): 64391


6. Developing the case studies

The previous chapters have detailed the planning process as a sequence of interacting but nevertheless distinct stages. The stages provide a framework for project planning and they can also function as a framework for presenting results of the planning process in an orderly fashion. In fact, it was this approach that was used when information was being gathered on the case studies that form the Appendix to this book. All members of the working group were instructed to write their case study reports according to the scheme laid out in Fig. 1.1. This was done to give the reports a certain uniformity in spite of the large diversity represented by the projects reported upon.

The case study reporting was further enhanced by subdividing the stages into more detailed categories. However, rather than providing a more elaborate outline for each of the stages, it seemed preferable to cast the different aspects of each stage into questions to be answered. A total of about thirty questions was found to be adequate to cover all stages, and these are listed in Appendix I.

6.1 The example case study

To help with the writing process, an example was prepared to illustrate how the case studies should be written and to give an idea of what kind they should be. It was apparent to the working group that large-scale international planning efforts on very large water resources projects are of less interest to the intended readership of this book than the everyday projects done in member countries. If a case study shows how useful systems analysis techniques have been (or could have been), a reader may be encouraged to try systems analysis techniques himself. This sort of reasoning led to the choice of the example, a small water resources development scheme designed for the single purpose of flood protection (with some side benefits of low-flow augmentation and recreation). This example (Case Study 1) was worked out and sent to all members of the working group to guide their own written presentations.

The choice of projects to be reported upon, however, was left to the members of the working group, and thus a healthy mix of cases was obtained. They range from a regional (Level B) study from the U.S. (Case Study 4) to an almost purely hydrological preliminary study done in Denmark (Case Study 7). Table 6.1 groups the case studies according to certain typical criteria.

6.2 Instructions used in formulating the case studies

Each case study begins with an introduction that outlines the planning situation in the country of its location, along with a brief description of the project and its origin. After this, the details of the study are given, explained by means of answers to the list of questions. All authors were instructed to follow the set of instructions listed below.

1. Case study reports should cover the entire project planning process, discussing one by one all of the five planning stages articulated in Figure 1.1, Chapter 1.

2. One of the major objectives of the entire effort is to cast applications of system analysis in terms of the real-world complexities of the planning process. While
discussing each of the planning stages, all the systems analytic methods applied should be described, and even unsuccessful attempts of application of methods offered by systems analysis should be illuminated.

3. Especially useful for the project will be background information that, while it may seem to be of no particular scientific value, may prove to be of critical value for project development (e.g., manpower limitation, lack of access to computing installations, too short deadline for results, etc.)

4. It should be recognized that the entire effort concerns itself with the process of projects planning. These projects may be of different character and magnitude; however, our interest is in the undertakings that were planned for a relatively immediate implementation. Long-term countrywide planning efforts of a strategic nature are beyond the scope of the work to be undertaken by our Working Group.

5. Case study reports should not be limited to water projects of a structural character. On the contrary, nonstructural projects -- such as as flood plain zoning, introduction of water conservation incentives via regulation, and water pricing -- will be of great value for preparation of the final report.

6. In all case study reports, the institutional framework should be illuminated. Who originally conceived the idea of the project? Who was charged with responsibilities for project planning? Did project initiation involve negotiations and bargaining among all parties concerned? Was it made clear right at the outset who would operate the project following its implementation?

7. In most cases planning is a process full of controversies. This leads to conflict situations which arise from the multiplicity of objectives and multitude of actors (experts and decision-makers) participating in the planning process. It will be particularly illuminating to discuss the ways in which conflict situations were resolved (including the application of both analytic and heuristic methods).

8. Uncertainties and risks are inherent in all planning efforts. It should be recognized explicitly how they were handled. This concerns project objectives, available data, model formulation, estimation of model parameters, etc.

9. Projects being discussed in these guidelines normally don't allow for development of any major data collection programmes. Their planning must be based on the data available at the moment of initiation. However, sometimes "crash programmes" for collection of certain absolutely indispensable data are organized. It would be interesting to illuminate such aspects of the data collection programmes.

10. Because of the particular interest of IHP in the hydrological inputs to the water resources planning process, the hydrologic data that were used should be explicitly recognized in the planning process. Problems related to the reconstruction of natural hydrology (streamflow series) are of interest, as well as the use of rainfall runoff models in the context of water resources planning.

11. In accordance with the overall objectives of this IHP project, it is important that the case study is presented in such a way that lessons can be drawn to improve on the planning process. What are the main impediments, and how should past mistakes be avoided? In this respect, retrospective analysis of already-implemented projects that were planned with the application of systems analysis methods will be of particular value.

12. These guidelines are not necessarily inclusive. Each author should discuss in his summary report
other pertinent aspects that he considered valuable and that contributed to achieving the stated goals and objectives of this IHP project.

6.3 The purpose and scope of the questions

The thirty questions, which were based on Figure 1.1, Chapter 1, were posed to all contributors to the case studies (see Appendix I). They were designed to cover all important aspects of the case studies that are related to project planning. The rationale for the thirty questions will be discussed next.

Planning Stage 1. Project initiation and preliminary planning

Five questions were directed at Planning Stage 1. The purpose of these questions is to identify objectives and planning staff.

Question 1--Was the project initiated on the basis of a long-term program?--was designed to set the case study into the perspective of national or even international planning, from which many but not all projects derive.

Question 2--What level and type of skilled personnel and agencies were involved in the various stages of the planning process? Was the public involved, in particular in the formulation of project objectives?--consists in fact of two separate but related questions. The first is concerned with the staff performing the study. The second concerns public involvement in formulating the initial plan specifications. This public group is not usually considered in the early planning stages of a project. However, it is the conviction of the authors of this book that a water resources project, carried out at any place in the world, must involve the people who are to be served by it. It is necessary for these people to be informed so that they fully understand the implications of the project and the benefits deriving from it, because this seems to be the most promising way to generate water resources projects that are of lasting benefit.

Question 3--What decision criteria were employed for project initiation?--covers the breadth of possible criteria that may be used in different countries and under different political and economic systems. The question was included in the hope of discovering some generalized conclusions that could be drawn on how to set up a water resources project, but the general finding was that the plan initiation very seldom proceeded from a basis that could be generalized.

Question 4--What constraints were posed?--was intended to find the types of limitations on water resources project planning that are accepted in different countries, such as issues of landscape modification or environmental protection. The intention was also to find out if such constraints which are established at the outset, whether they are negotiable, and whether they lead to limitations in the scope of the planning or the scope of the project.

Question 5--Did all experts agree on the methods to be employed?--was directed to the question of the composition of the planning staff and their compatibility. Many types of experts are not well acquainted with the concepts of system analysis. For example, an agricultural engineer who is an expert on water distribution systems may not see his part of the project in the same frame as the meteorologist who discusses the rainfall inputs into an irrigation system. The issue raised by this question is conflict resolution among experts during the formulation of a project.

Planning Stage 2: Data collection and processing

The second group of questions relate to Planning Stage 2, on the data involved and the mode of
gathering and analyzing them.

Question 6--What data were used?--concerns not so much the details of all the data but the networks that are available in various countries and the types of data that are being used in the analysis. Not everywhere is a network available; often it should be installed when it does not exist, but even more often it is not possible to do so. This is the subject of Question 7--Were only existing data used? But Question 7 goes further in suggesting that it is possible also to upgrade the data base by continuing measurements during the planning process, or even during the first phase of the operation of the project. In a more sophisticated planning effort, it is possible to trade-off length of data records against design uncertainty. To find out if such techniques were used, Question 8--Were OR techniques used to decide on the method of data collection and length of data records?--was asked. It is a difficult problem to obtain economic and other input data for optimization models, including monetary objective functions. It is of great interest to find out how such data are secured in different countries. This is the purpose of Question 9--Was a programme set up to take stock of and/or utilize criteria data? Finally, Question 10--Were any special methods used to analyze the data?--was aimed at the research aspect of data analysis and the special methods of handling such things as problem data bases or scarce or unusual types of data.

Planning Stage 3: Formulation and screening of project alternatives

The third group of questions concerns the formulation of project alternatives, Stage 3. One result of the planning initiation phase (Stage 1) is a later phase in which data are gathered and alternatives are formulated. Note that this process usually involves a project team. Thus, the first questions, Question 11--What resources were used?--and Question 12--What type of institutional support was provided for clearing the planning?--are designed to give a background on the planning team, while Question 13--To what extent did the public participate?--is intended to find out if the planning was done by agencies only, or whether screening of alternatives also involved the concerned public. Question 2, which also inquired about public participation, only covers the project initiation phase, whereas Question 13 was designed to add information on the level of public participation throughout the planning.

Often the public is confronted with a finished plan, and it becomes very difficult indeed for somebody who has not participated in the screening process to fully understand the reasons for the selection of the final project. Such considerations are already incorporated to some extent in the final questions of Stage 3. Question 19--Who made the final decision on the project?--and Question 20--Was it an interdisciplinary planning effort?--except that in these two questions the judgment of each case study respondent is called on so he/she can make recommendations on how this stage might have been executed for best results.

Questions 14 to 18 are directed toward the process of setting up a preliminary model for the purpose of selecting an alternative or alternatives to be investigated in detail in Stage 4.

Question 14--Were many alternatives investigated?--is a question whose answer obviously requires a number larger than one, because unless there is a choice at this stage, there is no decision process, and no Stage 3 exists.

Question 15--What was the hierarchical structure of the decision-making process associated with planning during Stage 3?--is an inquiry into the decision-making
process adopted by the team of planners and the method by which it asserted the support of the decision-makers. It is generally agreed that complex water resources projects must be worked on by experts of many different kinds. With such varied input, a team leader is needed who is authorized to override incompatible opinions and whose leadership is accepted. The second part of two-part Question 16--What constraints were imposed? Who imposed then?--addresses the same concern, while the first part is directed toward project model formulation, which depends on the constraints under which the planner must work.

Question 17--What models were used?--required a description of the models for the Stage 3 calculations. These calculations are based on rough estimates of inputs and costs; the calculations are done in just sufficient detail to permit selection of the final alternatives and, what is more important, to permit estimation of project costs and other consequences so that a final decision on the project can be obtained. Because models can be of very different degrees of reliability, Question 18--To what extent were these models tested, etc.?--is really a question about the expected accuracy of Stage 3 calculations.

Planning Stage 4: Development of final project specifications

Stage 4 begins when preliminary decisions concerning project configurations have been made, the funds for final planning have been made available, and all constraints and objectives have been detailed. At this point, the stage has not yet been reached for doing design, although the types of structure and the design conditions concerning their function within the project are known. Stage 4 consists of quantifying information on design discharges, operation rules, etc., within a system model in which interactions of all system elements as well as trade-offs among objective functions (if any) have been quantified.

Question 21--What OR methods were used?--concerns the methods of analysis by which the final project and its operation were specified. The next two questions, Question 22--Did you use cost-benefit analysis?--and Question 23--Did you make a risk or impact analysis?--add important details to the response to Question 21, because these two types of analysis yield the most important decision criteria for final plan selection and project implementation decision. The same is true for Question 25--What procedure of trade-off analysis was followed with respect to environmental vs. economic issues?--except that this question is more concerned with the details of the analysis technique than with presentation of the results. These analyses, which were already part of Stage 3, are repeated in Stage 4 for final decision-making. They are perhaps made by a group who have had more direct access to engineering cost information. Stage 4 must involve experienced engineers, preferably those who will do the final design in Stage 5.

Question 24--How were the preferred plans selected?--is directed at finding out how the engineering experts interacted with nontechnical persons in the decision-making process within the constraints of previous decisions. Question 26--Did the decision-maker accept the optimum solution?--is the ultimate question of this kind. It seeks to determine whether the project was actually designed according to some optimum (preferred solution) identified in the systems analyst's recommendations or whether the final design proceeded along conventional lines. Question 27--What was the process leading to the approval of the final plan--then, is the final step in the decision process leading to the final go-ahead given by political bodies, which will usually also have to make available the funds for the project. This question and Question
28--What was the process of funding the final plan--are different aspects of the same question and must be answered together. Quite a different kind of problem is addressed by Question 29--Was any post-planning evaluation carried out? Usually the planner of a project receives very little feedback from the operators of the finished project. Thus, very little is known about whether water resources projects have really performed according to plan or, if they have not, which one (or more) of the aspects deviated from the design assumptions. Future designs should be allowed to benefit from experiences with existing projects, particularly in assessing the need for data requirements.

Planning Stage 5: Project design

The final question related to Stage 5 was Question 30--Were the design drawings part of your job? This question was asked in order to find out how closely designer and planner were associated. It is generally assumed that a project specified in Stage 4 must be accepted not only by the decision-maker, but also by the design engineer, who in the past has usually been the same person who did the planning. How did he or she react to having a planner tell him what design specifications to use? It is possible that experience obtained during the case studies may be used to increase cooperation and collaboration between planner and designer.

The planning process, as broken down into thirty pertinent questions, provides a guide by which project planning in water resources may proceed. If a water resources project planning team is able to answer all these questions, then it is likely that the experts have done a good job of drawing up a complete plan.

Some of the experiences which the members of the working group had in their studies or in planning projects will be summarized in the next section.

6.4 Some conclusions from the case studies

The type of case study submitted by members of the working group might have been to some extent determined by the sample case study chosen and the specifics of the questionnaire. However, the case studies had already been submitted before the example was prepared, so most members can be assumed to have been free of the straightjacket of a given prior example. It is therefore remarkable that regional projects dominate so greatly. It seems that this planning level is particularly well suited to water resources planning. This is because most regional studies involve river basins and therefore operate within natural boundaries and largely within constraints and objectives set only by demands on water. On a large scale, for example at the national level or for a large economic region, water and its use and distribution tend to become just one concern among many others. This means that in projects on a national scale, objectives and conflicts may surface which will not be well understood by water resources planners, most of whom have an engineering background and serve in an engineering department of an agency or university. On the other hand, a small-scale water resources project can degenerate into merely the design of hydraulic structure(s). Such a problem might be quite demanding for a design engineer but will involve rather limited scope for planning.

The preference for case studies that report on planning regional projects is undoubtedly also dictated by the fact that, on this level, water concerns dominate the decision process of a water resources project. Under such conditions, there apparently are not many other conflicting interests. Once the 'decision-maker'--usually a ministry of a high-level government agency with broad
powers—has determined that the water resources of a region are to be developed, the execution of the planning process is left to engineers, who use their best judgment in deciding alternatives and structures that will accomplish the objective of water resources development. These engineers use the best methods available to them: the projects that have been described in the case studies have mostly been cases where the desire to do the job as well as possible has led in a natural way to the use of a more or less comprehensive systems approach. Although many regional water resources systems have been developed or planned without the use of systems analysis and operations research methods, it is likely that the number of projects developed in this manner will decrease in the future as more engineers familiar with such techniques are entrusted with water resources planning.

It is remarkable that one study (Case Study 10, by Becker and Korzerski) shows that it is possible to develop a standardized or almost standardized approach to solving typical water resources problems in many different sub-basins of a river. In such a case, systems analysis has become a state-of-the-art technique which supersedes all previous techniques—a state of affairs that has not been reached in many countries. It likely requires a degree of acceptance of systems techniques which can only be obtained if the decision-makers concerned with water projects thoroughly understand the potential and the limitations of the systems approach to water resources planning.

Very little has been said about the inclusion of operation rules or schedules in the optimization and the specifications derived from them. This is unfortunate, because it is one of the great hopes of water resources planners that, by providing optimal operation rules for reservoirs or other water distribution systems, they can materially improve the utilization of water resources. Some information would be desirable on how well the systems that operate on optimized operation rules are performing. It seems likely that operators would steer a safe course by using optimized rules that yield an optimum (on the average) when no forecasting of future events is included. These can be supplemented by individual adjustments based on experience with the actual operation of the system, thereby achieving enough operational flexibility to be able to adjust to later changes of objectives or operation rules.

It is also noteworthy that no case study makes references to an operational forecasting model that permits adaptive operation based on real-time hydrologic events. One reason for this may be related to the fact that these water resources systems perform fairly well without real-time forecasting of future demands or supplies, and the performance can be improved only by forecasting extreme events that are extremely rare.

An example of this state of affairs is the forecasting of floods in small catchments. In principle, there have been a number of research studies that show that an improvement in flood protection can be obtained through real-time forecastings with Kalman filters or by means of satellite or radar evaluation of rainfall. However, the operation implementation of a forecasting system in a small catchment is not cost effective. It is not useful to install a system that will be used only once every fifty or so years. The forecasting procedure must become part of a multipurpose forecasting activity, where economic feasibility is dictated by other uses.

The case studies also show very little actual optimization in the sense of determining the optimum of an objective function. Simulation is the most common method used for planning, and the figures of merit
are mostly probabilities of meeting target objectives. This is particularly well expressed in the method advocated in the case study by Becker and Kozerski (see Case Study 10). It seems that it is generally easier for the "decision-maker" to base his decisions on a multitude of such figures of merit, which he then evaluates, not according to objective criteria but according to his subjective impression of their relative merit. Indeed, anyone who has been involved in the decision process of a water resources project has found that costs or other rational objectives are very seldom used as criteria for making the final decision. The deciding factor is political acceptance, which is based on perceptions of relative merit as compared with other uses of public funds. Even in cases where cost-benefit or similar economic criteria play a role in the decision process (in internationally funded projects, for example), optimization is rarely ever employed because of the difficulty of expressing different objectives in commensurate terms. Multiobjective analysis methods developed over the past two decades may overcome this problem in a way that is acceptable to the decision makers.

As a final observation, most of the studies included here involved not only water resources planning staff from an agency of a consulting firm, but they were also accompanied by university teams, which were often research teams. It is evident that through research and study of the international literature, the advantages of systems analysis have become apparent to academics earlier than to other planners—in part certainly because of their information advantage, but in part probably also because academics can spend more time in following new approaches than professionals, who usually work under very tight monetary or time constraints. This situation is typical for a developing field. The academic will tend to simplify problems to make them fit the methods of solution that he knows; when he works with a practitioner, he will find the flaws and gaps in his knowledge, which will prompt him to further develop and adjust his methods. This process of feedback and adjustment continues until either the new methods become too complicated, at which point they find a final resting place in the pages of a professional journal, or until they have been forged into a generally acceptable tool that becomes part of the professional know-how. It seems that up to now in the field of water resources, mostly simulation techniques have reached the latter stage. Only time will tell, after a great deal of cooperative effort involving universities, government agencies, and consulting firms, if more sophisticated decision models will be suitable for general project planning.

The current state of affairs might be summarized as follows. Many of the Unesco member countries have teams of people who keep trying to improve the planning methods for water resources projects. If this book helps to encourage them to continue their work and see their project as part of an international effort at understanding and improving the planning process for water resources projects, it will have served its purpose.
Appendix 1: The questionnaire

This appendix contains all the questions that were used to outline and give regularity to the case studies that follow. They are grouped under headings that represent the five planning stages outlined in Chapter 1.

Planning Stage 1: Project initiation and preliminary planning

1. Was the project initiated on the basis of a long-term program?
   Discuss briefly.

2. What level and type of skilled personnel and agencies were involved in the various stages of the planning process? Was the public involved, in particular in the formulation of project objectives?

3. What decision criteria were employed for the project initiation?

4. What constraints were posed? What constraints posed the greatest problem? Who imposed them? Was there willingness to discuss these constraints?

5. Did all experts agree on the methods to be employed? How was an agreement brought about? (Decision by decision-makers siding with one of the opinions? Decision by a planning bureau?)

Planning Stage 2: Data collection and processing

6. What data were used in terms of type, scope, frequency, spatial and temporal distribution, etc.? Please address both hydrological and nonhydrological data (e.g., demographical, socio-economic).

7. Were only existing data used? If not, what methods were used to get new data: synthetic generation? new measurements? Were measurements continued during the planning stage? during the construction?

8. Were OR techniques used to decide on the method of data collection and length of data?

9. Was a program set up to assess the availability of the data base used? Who managed such a program?

10. Were any special methods used to analyze the data?

Planning Stage 3: Formulation and screening of project alternatives

11. What resources were used in this phase of the planning process, e.g., time, funds, computers, facilities, and manpower?

12. What type of institutional support was provided during the planning process, its sources, and its impacts?

13. To what extent did the public participate in the planning and decision-making process?

14. Were many alternatives investigated? In what detail? Who decided on the alternatives to be investigated?

15. What was the hierarchical structure of the decision-making process associated with the planning of the case study discussed? Who made what decisions? How was conflict resolution achieved? How were trade-offs assessed—explicitly or implicitly?
16. What constraints were imposed? In your opinion were they reasonable? Acceptable? Who imposed them? How hard were they? Could they be relaxed by discussion? By decision-makers?

17. What simulation/analytical models did you use and for what purpose? Which of these models were developed elsewhere and which were developed during and for the project?

18. To what extent were these models tested, calibrated, verified, and modified?

19. What was the role of the technical experts, the decision-makers, and the public in the final selection of the final plan?

20. Was it an interdisciplinary planning effort? Was the mix appropriate? What conclusions and recommendations can you share?

Planning Stage 4: Development of final project specifications

21. What OR methods were used? For each method: did you use existing models for your project? Did you use new developments, modifications? Your own? Where did you get them from? Did you find the literature useful? Which book or paper was of particular value? Did you adjust the problem to fit the model? Was the model "optimized"? Did you explore many different methods? How many? How did you decide on the one you used? Would you use it again? How much time did you spend on this?

22. Did you make a cost-benefit analysis? What did you learn from it? Would you recommend doing that again?

23. Did you make a risk analysis/impact analysis? Why: was it required by a decision-maker, or by whom? What did you learn from it?

24. How were the preferred plans selected? How were trade-offs assessed? Were specific trade-offs generated? Was a multiobjective optimization methodology used? How involved were decision-makers (at the various levels) in this selection process? What conclusions and recommendations can you share?

25. What procedure of trade-off analysis was followed with respect to environmental concerns vs. economic concerns and objectives?

26. Did the decision-maker accept an "optimal" solution generated by the models? Did he accept your approach or was it supplemented by "conventional" information?

27. What was the process leading to the approval of the final plan?

28. What was the process of funding the final plan?

29. Was any post-planning evaluation carried out?

Planning Stage 5: Project design

30. Were the drawings part of your job? Who did them?—another group, somebody in your office? Could you relate the systems analysis results to the designer?
Appendix II: Case studies

This appendix consists of ten case studies. They are arranged in alphabetical order, with two exceptions. Case Study 1, E.J. Plate, was written to provide an example of how to structure the case studies for this appendix. This example was sent to all members of the Working Group, and to the other contributors.

Case Study 10, by A. Becker and D. Kozerski, was not structured according to the example of Case Study 1. It is a brief description of a general procedure based on simulation methods for planning water resources projects, and it supplements the process expressed in Chapters 1 to 5. Rather than integrating this method into the text, the Editorial Board decided to leave the paper as a general contribution to the overall subject.

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PLANNING A SYSTEM OF FLOOD PROTECTION RESERVOIRS IN
THE SULM CATCHMENT IN THE FEDERAL REPUBLIC OF GERMANY

By

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1. Introduction

The industrialization of Germany has brought urban developments and factories into river flood plains which in older days were flooded regularly by rivers swollen from heavy summer rains or early spring snow melt. The traditional method of flood proofing consisted of river training and construction of flood levees - measures which tend to alleviate the flood hazard in the protected region but increase magnitude and shorten concentration time of the floods downstream. The hydrological design information for these floods is obtained in a straightforward manner by extreme value analysis of the extreme flood peaks, often using the procedure 111 recommended by the German Water Resources Association (DVWK), which is based on the Pearson III and Log Pearson III curves. By means of hydraulic calculations flood peaks are converted into stages for the newly designed cross sections. The cross sections usually are obtained combining experience with empirical design considerations, although a model has been developed by Seus and Bauch in which LP is employed to yield a combination of cross section geometry and levee height which requires a minimum cost. The model has been described in 121 and it has been applied to some Bavarian rivers by the authors.

Recent practice has been to design a system of flood protection reservoirs, by means of which the floods from the upper catchments are retained and released after the floods from the lower reaches have receded. The practice has the advantage that apart from the widening of narrow sections and channel improvements the lower parts of the rivers are kept free of engineering structures, thus preserving them in their natural state while at the same time obtaining flood protection for the downstream areas. Since this practice of flood proofing is used quite extensively in West Germany, it is useful to present a case study on it as a contribution to the IHP as part of the experiences of Unesco member countries with operations research methods, in spite of the fact that systems analysis and OR methods are used only marginally.

The system considered is the Sulm catchment shown in Fig. 1. It is typical of many systems which have been designed and constructed in the Federal Republic of Germany in recent years, but it is not typical in these respects: first,
Fig. 1: Planning area
the area has been exceptionally well equipped with gaging stations for runoff and for rainfall, permitting fringe studies on the effect of network density, regionalization of unit hydrographs etc. which eventually will lead to recommendations for procedures to be applied in future systems.

Secondly, a research team was available (Institut Wasserbau III of the University of Karlsruhe, IWK) which was not only interested in solving the problem at hand but also in using the data of the study area for research purposes, so that the cost of the data evaluation was covered in part from research funds. Thirdly, the research team of the IWK was interested in applying OR techniques to obtain an optimal solution, although traditionally this problem is solved by engineering judgement and consensus of the communities involved without formal application of OR techniques.

A common feature of many Germany flood protection schemes is that the sites available for building flood protection reservoirs are few, limited in size, and located usually so far upstream that only a small part of the runoff from the catchment can be retained by the basin. Therefore, the problem posed usually is this: what is the probability of occurrence of the maximum flood that the system can protect against, and what is the minimum size of the reservoirs at the possible locations to accomplish this protection. Usually this problem is constrained by innumerable local conditions ranging from the desire of the population of one village to be protected against a 100 year flood to that of other villages who would like to have a very small or no reservoir so as to be able to use the area for other purposes. Also, flood protection by reservoirs can be supplemented by river training measures.

In order to illustrate the planning process for such a system, the questions of our questionnaire will be answered in sequence.

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1:

The project was initiated through two developments: the provision of the legal framework for flood protection measures through state and federal laws, which regulate the financial responsibility and the procedure for setting up flood protection systems. In particular the laws require setting up a district formed by the profiting communities, which must pay 30% of the cost, while the rest of the cost is covered by state and federal sources, subject to approval by the State Parliament. In this sense, the project is part of a long range plan to protect all citizens of the country against natural disaster. The second step was taken after a severe flood in 1970 caused extensive damage in the city of Neckarsulm.

A flood protection district (FPD) was formed, which agreed to distribute the cost according to a cost sharing plan worked out on the basis of share of benefits and financial capability and negotiated by the local county administrations. The district in cooperation with the state water administration (SWA) worked out a preliminary plan, setting aside possible sites, and submitted it for approval to the State Legislature which authorized the planning and construction of the system, allowing a certain budget per year for State support - and thus, since Federal Support is on a cost sharing percentage, also for Federal funding. With the green light thus given planning proceeded in earnest, resulting in the hydrological calculations and the planning recommendations of the IWK.

Question 2:

The state of Baden-Wurttemberg maintains a competent staff within the area bureau of the SWA capable of handling all technical and administrative tasks. The public was involved, through the community
councils, in the setting up of the FPD. The public was thus involved indirectly.

**Question 3:**

Decision criteria were: what was interpreted as the desire of the people to be protected, which surfaced after the 1970 flood, and the availability of funds. But perhaps the deciding factor was that the Audi-NSU works, which in 1970 had suffered a flood damage of about 10 Mill. DM, threatened to move to another location unless its site in Neckarsulm was protected against floods similar to the 1970 flood. Since one reservoir (Breitenau, see Fig. 1) was large enough to contain more than the 100 year flood of the upstream region, storage in it was set aside for low flow augmentation for exceptionally dry years, which during ordinary years allowed some utilization for recreation.

**Question 4:**

The constraints were set by the land available for the system, by the fact that due to other activities (recultivation of vineyards in the area) one of the reservoirs had to be started before planning was completed, two reservoirs in the river had already been constructed before 1970, and funds were available to start the construction of one basin right away. The planner (the local representative of the SWA) had to make preliminary decisions without the benefit of a sound hydrological basis.

**Question 5:**

The main experts on the project were: the water reservoir planner and hydrologic analyst, i.e. the IWK, and the representatives of the SWA, in particular the local representative, who also provided the liaison to the higher echelons and to the FPD. All technical decisions and models were discussed with him and occasionally with members of the regional administration. According to the administrative structure of the SWA the decision-maker on technical aspects is the local representative. He fully cooperated and accepted the results of the planning hydrologist.

**3. Planning Stage 2: Data Collection and Processing**

**Question 6:**

The data base for the study consisted of hydrological data on rainfall (rainfall gages with daily totals measured everyday, and recording gages) and runoff (runoff gages at the locations shown in Fig. 1). The rainfall gages with roman numerals had been observed for 7 years, but long term records from 1950 -1977 were available at stations near the Sulm area and were used to obtain long term statistics. For long term runoff statistics the runoff gage at Neckarsulm was used for the period 1956 - 1977.

All years of the records were used to obtain extreme value statistics, and to identify floods and shapes of flood waves. The network density with 18 raingages for 110 km 2 was far larger than average, because after the flood of 1970 the area had been made a study area of the ministry responsible for the water administration. It is more usual to have rain gages one every 100 to 500 km 2. Also, the runoff gages on the small creeks are an unusual feature, but they permitted to regionalize runoff unit hydrographs, and the data have been used (by us) to work out more general rainfall-runoff relations. Economic data were not required, except for the cost of construction for the reservoirs. The very dense network of gages was set up with the additional purpose of yielding information on the required network density for studies of the same kind as the one reported on.

**Question 7:**

For flood protection studies flood waves of certain exceedance probabilities are required. Naturally, such data had to be
obtained from the basic data by extreme value analysis of the rainfall and runoff data. The flood waves were obtained by using rainfall waves calibrated against measured waves, whose area was obtained from a generalized depth-area-duration curve for rainfalls of different exceedance probabilities of the area's subregions. A constant runoff coefficient was used which was determined from a coaxial-diagram of the area, and a regionalized unit-hydrograph was used to obtain the runoff hydrograph. When possible, the extreme value of the calculated runoff hydrograph was checked against the extreme value of the measured runoff of the same exceedance probability and the coaxial-diagram was (slightly) adjusted to improve agreement. The data collection continued throughout the planning stage, and floods were used to verify unit hydrographs (usually with little need of adjustment), in particular a major flood in 1978 which proved to be an event whose probability of being exceeded was about once in 50 years.

**Question 8:**

No OR techniques were used to determine the method of data collection, but the unusually large amount of available data triggered a number of studies: on the optimum control of flood protection reservoirs [3], on the density of networks required for flood protection work, on the accuracy of rainfall determination from networks of different density. However, the study itself did not require OR techniques in the data analysis stage other than least squares analyses used for curve fittings.

**Question 9:**

The objective function of the study did not require criteria data. In particular, data collection and objective function of the study were not coordinated. As has been stated before: there exist in Germany networks of rainfall and runoff gages which are operated by the Meteorological Service and the state Water Authorities, respectively. It might be interesting to ponder the history of these networks: certainly their originators had no notion of the purposes for which the data basis is being used today.

**Question 10:**

The project served to develop a hydrological method of flood calculations for multisite reservoirs. The method consisted of adapting an area rainfall-runoff model to the Sulm area, by using the regionalized unit hydrographs described above for each of the reservoirs which were located on tributaries, and by using linear flood routing for the river parts between the reservoirs on the main river. Models of this kind had been developed in different parts of the FGR (Schultz [4], Bogardi et al. [5], Schroeder and Euler [6]).

4. Planning Stage 3: Formulation and Screening of Project Alternatives

The project alternatives in this particular case were given by different combinations of reservoirs, with only reservoir Breitenau used also for low flow augmentation. Consideration was given to use the low flow storage for recreational purposes, although the opinions on this were mixed. Although it was realized that the area would benefit economically to some extent, due to the purchasing power of visitors, there were fears, born out of experiences in nearby regions, that the visitors would place a burden on the environment, and that the maintenance of parking zones, beaches, and the like would cost more than would be gained by the region - in particular since most visitors would come from nearby large cities located outside of the region. However, because it was felt that the reservoir would be used recreationally anyway, the decision was made, to establish recreational facilities at the lakes. But no detailed benefit-cost analysis or any other planning
instrument was used to support the decision. The answers to pertinent questions of this section refer to the alternative combinations of reservoirs only.

Questions 11 and 12:

The alternatives were investigated by the hydrologists of the University of Karlsruhe. In part supported by state funds for the project, and partly by research money from the German Science Associations, a number of staff members worked out the programs. All in all, a total of about 6 man years were used, of which only a fraction of about 9 man months was used for the actual project, the rest being used for research. The computer facilities of the University of Karlsruhe are available, free of charge, as the University provides this service for research and since the University is a state institution, other state institutions like the LWA can be serviced by the University (in this case by the IWK).

Question 13:

At this stage of the planning process, no direct citizen participation took place. But indirectly, of course, the citizens had already restricted the possible sites and sizes of the reservoirs, which were entered as fixed quantities in the planning process. Thus it was possible for the modeller to reduce the size or throw out altogether some of the reservoirs, but not to increase them nor to select new and additional locations.

Question 14:

A total of 7 alternatives were investigated. The objectives of the study were to obtain a maximum protection at the least incremental cost. For example, if by building an additional reservoir the flood downstream could be changed by only a few percent, it was considered more useful to increase the capacity of the creeks slightly rather than to buy an expensive reservoir. The decision on the feasible alternatives were discussed between the IWK and the local representative of the SWA.

Question 15:

The hierarchical structure was fairly simple. Since the structure of the decision process is set by law, the decision rests with the district board which is advised by the SWA. The IWK and the local representative of the SWA together worked out the alternatives to be subjected to detailed study and the ones to be presented to the echelons of the SWA. The final project plan was developed in a joint meeting of IWK, all levels of the SWA with interest in the case, and representatives of the FPD.

Question 16:

Already discussed in answering question 10

Questions 17 and 18:

The method employed was simulation by means of design rainfalls of different exceedance probability. The results of each alternative were scrutinized by the planning team, and the alternative was selected which seemed, by intuition, to meet most of the purposes and constraints. There was no OR method employed in the decision process.

Question 19:

Although the SWA and the FPD share the responsibility for proposing the final project, the recommendations are mostly those of the model builder (IWK). The reason is that the University is considered most qualified to solve complex planning problems. The decision to implement the study is made by the FPD with final approval required by the responsible ministry before actual construction, as is described in connection with question 27 below.
Question 20:

Most of the planners were civil engineers or hydraulic engineers. However, through the hearing mentioned in question 27, experts of other agencies are included, but their contributions are made mostly during the planning stage 4.

5. Planning Stage 4: Development of Final Project Specifications

Whereas stage 3 was designed to give a basis for selecting the alternatives most likely to satisfy the objectives, stage 4 is concerned with the detailed investigation of the final plan. It must be realized that stage 3 is a stage in which not all the data are used, nor are all necessary calculations made. In stage 3 only those aspects are covered which vary from alternative to alternative, and the final decision for stage 3 is made not on the detailed plan, but on the basis of preliminary drawings.

The aspects which are investigated in stage 4 are first the determination of operation rules, then the evaluation of the system under a given set of operation rules for floods of different recurrence intervals. Finally, the optimum sequence of building of the reservoirs was decided on.

Question 21:

OR methods were employed for determining the optimum operation rules. It was assumed that the hydrological model described in connection with question 10 provided the flood waves for which the system had to operate optimally. Originally, an active control was envisaged by means of which the operation of all reservoirs was to be controlled. The objective function chosen was the operation which minimized the flood peaks of the flood wave released from the reservoir (Plate and Schultz [3]).

The method was originally based on two reservoirs only, but in a later study (Meyer-Zurwelled [7]) it was extended to up to 16 reservoirs. Incremental dynamic programming was used, and applied to a group of 4 reservoirs each of which being a lumped group of up to 4 reservoirs. The operation of the lumped group was first determined as if it consisted of a single reservoir, and afterwards the optimization within the 4 reservoirs of the lumped group was made with the share of the flood allotted to the group during the first optimization step forming the constraints to the subproblem. The improved operation of the group then was once more lumped and iteratively the problem of 4 lumped reservoir groups and the problem of the distribution of floods within the groups was solved until further iterations brought no additional improvement. It turned out that the gain in system performance of a 16 reservoir system as compared to a system in which each reservoir is operated independently of all others was rather small, because of the small size of the catchment and the short distances between reservoirs. Recent research in the Federal Republic of Germany is directed to finding operating rules that work adaptively on the basis of a rainfall forecast and the forecast of hydrograph parameters. Radar methods are being employed for the rainfall forecasts (Schultz, Anderl et al. [8]). Real time runoff forecasts are developed on the basis of Kalman filters. However, the results are not yet satisfactory enough to yield methods for systems as small as the one described, and there exists some doubt that it will ever be useful to use forecasts for a system that needs to be operated optimally once on the average every 30 to 100 years. With this in mind, a different method was employed by finding operation rules based on the hydraulics of usual outlet structures and spillways for reservoirs which are set permanent in such a way that the systems performance under the set of 100 years design floods was as close as
possible to the optimum. This was found by trial and error.

Operations research methods were also used to decide the optimum sequence of construction. The original idea was to optimize sequence and scheduling in such a way that savings due to postponement of construction were balanced against possible losses incurred if a flood would happen before the reservoir was completed. This problem was formulated and a solution developed based on branch-and-bound techniques (Bogardi, 1979). However, there were two handicaps which prevented the execution of this programme: the lack of economic data on losses, and the financial constraints imposed on the construction, for which the state has set aside a constant amount every year with the total to be expended after 10 years. Therefore, the final decision on the sequence was made on the basis of efficiency of flood protection at the critical point (the Audi-NSU automobile works in the city of Neckarsulm at the mouth of the Sulm river): those reservoirs were built first, which brought the largest flood protection gain at that point. In case of equal benefit, a series of other critical points were identified (village centers or industrial areas on parts of the Sulm or its tributaries with small flood channels) and that reservoir placed first in the sequence of the remaining reservoirs which would cause maximum benefits at other critical points.

There is no question that all the methods employed had been used before. However, the problem had not been posed in the same form so that most of the existing methods had to be adapted, and no algorithm existed which could be employed straightforwardly, except of course such routine programs as used for matrix calculations. It seems to us that in similar situations only the logic as employed by us is feasible: to generate, on the basis of hydrological models, families of flood hydrographs, for each of which the reservoir system’s optimum operation rules based on perfect forecasts are found. These rules are then analysed to find the ones which would yield the best non-adoptive operating rules. There may be differences in the methods of analysis due to the situation encountered and the data base available (but a hydrologic data base as extensive as the one used for the present studies is usually not required. Unfortunately a detailed analysis of the required size of a network for small areas is still not available).

Question 22:

No cost benefit analysis was made. In any case, it is felt that the basic decision of building the system has little to do with cost-benefit, since alternative ways of flood protection (object protection, flood insurance) might be most cost effective. More important are the concern of the public and the availability of funds. Flood protection in the FRG is a political issue on the one hand, and a matter of economics on the other hand. Economics enter for example if an industrial plant is to be located in a flood prone area.

But it should be mentioned that the Federal Water Law requires that all projects be subjected to a cost benefit analysis. Because of this requirement, one of the most intensive area of flood research in the Federal Republic of Germany is concerned with the economic side of floods (Buck et al., 1979). There are a number of research projects in this area, and attempts are being made by different groups to obtain the necessary funds to conduct case studies.

Question 23:

Neither risk analysis nor impact analysis was performed. German authorities consider that risk analysis is not required for public water works if the standards (DIN 19700) are met. However, there is at present considerable concern
to provide a unified basis of risk analysis for all public works. The Federal Ministry on Research and Technology is sponsoring a research program on risk analysis, and first attempts have been made to provide a framework of risk analysis applicable to flood protection reservoirs on the basis of reliability theory (Plate 11).

An environmental impact analysis has not been performed. The reservoirs are blended into the landscape, landscape architecture is heavily employed. Water quality problems arise only in context with the recreationally filled reservoirs, and a program will be set up by the SWA and the FPO to survey and if necessary control the quality of the water. In fact, the usefulness of this survey became obvious soon after completion of the reservoir Breitenau, in which a shallow area was found eutrophied after a few months, and which had to be deepened by additional excavation. However, this is not part of the planning. Other environmental concerns, voiced at the hearing mentioned in question 27 could be met in the final design stage. As a result of objections by environmentalists, one of the reservoirs was eliminated to protect a wetland area. Also archeologists expected to find traces of ancient settlements at some of the sites, and special care was used during excavations, but nothing was found.

Question 24:

The selection of the final plan has already been made in principle at the end of stage 3. Here, only the final operation rules and final sizes were determined, which was mostly a technical matter decided by the SWA in consultation with the IWK. Small changes occurred in the design stage following stage 4, but they were dealt with locally.

Question 26:

The decision made followed to the letter the recommendation of the IWK. This is because the final report in which the recommendations were put down was prepared in cooperation with the SWA. A first draft was sent to them for comments, if they felt that they were unable to accept one of the recommendations. A compromise was found in which the hydrology was not questioned but a reduction was made locally of exceedance probability for the flood returned by the reservoir according to the value of the properties in the flooded area. No OR techniques were used for this.

Question 27:

Approval to the final plan is given by the county administrator (Landrat) on the basis of the plans submitted and approved by the FPD. The Landrat's approval is given for each reservoir separately, and only if there are no objections to the project from other potential users, which might be private parties or other Government agencies like the State Highway Department or the Department of Environmental Protection. In order to coordinate all objections, a public hearing is conducted (called "Planfeststellungsverfahren" or "Procedure of finalizing the Plan"), in which the county administrator (Landrat) or a more direct representative of the responsible ministry (of Environment and Agriculture) is trying to settle all open questions and to decide on pending issues. At this hearing, the public is invited, and all objections can be voiced by anyone. The state can refute or confirm the objection upon hearing of expert witnesses. If all objections are met, the plan is accepted; if some of the objections are not met but overruled by the official, the plan is also accepted, but the overruling might be appealed to a court, which is independent of the ministry.
**Question 28:**

Funding was done through a part of the budget earmarked for flood protection. This is distributed by the responsible ministry over all projects in the state of Baden-Württemberg, according to a list of priority worked out in the ministry. The present project receives about 2 Mill. DM per year, and construction must progress according to availability of funds. The total construction will be completed in 1990.

**Question 29:**

Due to the alertness and the personal interest of the local representative of the SWA, the project is closely supervised and improved through local efforts. An automatic flood warning system is being installed. And after each flood (in particularly after the 1978 flood) a careful evaluation of the system performance is carried out, including a recalculations of the hydrology after the 1978 flood by the IWK.

**6 Planning Stage 5: Project Design**

**Question 30:**

The planning results included: the sizes of the reservoirs, the operation rules for the reservoirs, the maximum discharges in the rivers and canals connecting the reservoirs. Also, the sequence of building the reservoirs was decided. With this information, the SWA usually would make a limited competition, inviting renowned consulting firms to bid on the design, and on the supervision of the construction. The successful bidder would prepare the drawings, subject to approval by the SWA, and the construction was initiated thereafter. In the present case, the SWA had the experience and the man-power to do the designs itself, and bids were requested on the construction only. The system is under construction, a total of 5 reservoirs have been built, and the partially completed system, containing the biggest reservoir (Breitenau), already had its first success when an extreme flood (exceedance probability in some localities of once in 70 or more years) occurred in 1978.

In fact, calculations after this event have shown that if the Audi-NSU works had been subjected to the same flood with the reservoir system existing in 1970, the damage at this location alone would have been 90 Million DM – exceeding the cost of the system by about a factor of 8.

**Acknowledgement**

The success of the project is in large part due to the efforts of the local representation of the SWA, Mr. H. Trost, Wasserwirtschaftsamt Heilbronn. He also provided many details of this report.
References

[1] E. Mosonyi et al. 1979 "Empfehlungen für die Berechnungen der Hochwasserwahrscheinlichkeit (Recommendation for the calculation of flood probabilities)" Committee on Design Floods, DVWK (German Water Resources Assoc.) Recommendation Nr. 101


1. Introduction

The Eastern Negev region covers some 2500 square kilometers of desert land in South of Israel. It is characterized by large differences of altitude between +150 m above m.s.l. in the west and +600 in the east. The region includes five towns (160,000 inhabitants), thirteen villages with extensively irrigated agriculture, two industrial centers, mainly chemical, and two phosphate mines. The climate of the region is arid (less than 200 mm rain p.a.), thus water requirements of all user sectors are relatively high, with a peaking distribution.

The area is at present in a rapid process of development and the annual water demand is expected to double - from about 50 MCM at present to about 100 MCM at the end of the decade. A major increase is expected in industrial and municipal fresh water demand.

The water supplied to the region comes from three sources: import of water from the north via the national water supply system (25% at present), local ground water (65%) and reclaimed effluents from local sewage.

Fresh water is being supplied by two separate pipeline systems, one fed by local ground water and the other by the national system. Both systems convey water eastwards through long lines and a series of pumping stations to overcome the long distances and large altitude differences.

The water supply development plan was expected to address the following issues:

a. The division of supply between local and imported sources (annual and seasonal).

b. The development and possibility of interconnection between the two systems.

c. The sequencing of development in time and space.

d. The seasonal variation in the operation of the integrated regional supply system.

Saline groundwater and sewage effluents are also used in the region, and are part of the development plan. However, in the following only the development of the fresh water system used for domestic, industrial and irrigation purposes will be discussed.

The resulting plan is an integrated water supply scheme, connecting all the sources and
users. Previous plans divided the area into separate water supply schemes: mainly the northern branch and the southeastern branch.

The investments required to expand the existing scheme to the "1990 level" are estimated at $20,000,000.

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1

The plan was to fit into an overall master plan for the region, in which the development of settlements, population, agriculture and industry were laid out and integrated. Such master plan does not exist explicitly. Sectorial plans for agriculture, industry and municipal development could be considered as a planning framework. The purpose of the project was to prepare a 20 year plan for the development and expansion of a water supply system which exists in parts of the region.

Question 2

The plan was prepared by TAHAL, which is the national water planning authority. Two W.R. systems engineers, one programmer and one student worked in the study.

Water supply in Israel is the responsibility of national agencies, which represent the interests of all consumers and the public at large. Therefore, no need was seen for the public as such to participate. However, representatives of the consumers, especially farmers, voiced their concerns and opinions on various occasions, and thus had an input to the planning process. The initiation of planning was required by local consumer organizations.

Question 3

The single objective of the plan was to fully supply the increasing water demand at the least overall cost. Decision criteria beyond the economical efficiency, such as maintaining existing activities and promotion of economical activities, daily life and amenities in the region, were only implicitly considered.

Question 4

Three main types of constraints were posed:

a. A given forecast of consumers' water demands

b. Limited production potential of local sources and limited capacity of the national water supply system.

c. The limited hydraulic capability of the existing systems.

a. The problem of demand forecasting was difficult for a number of reasons:

- For industrial uses the development plan and schedule were uncertain, and the water quality requirements not clearly enough defined.

- For municipal uses the main problem was the gap between the optimists and the pessimists concerning the population growth and pace of physical development.

- For agricultural uses the future cropping patterns are hardly predictable and therefore the total demand as well as the time distribution of the annual allocation and peak demand are dubious.

b. The production constraints of the national system are twofold: the nationwide scarcity of water in the system and the limited capacity of a 42" Dia. pipeline (Zohar-Zelim) which will be capable of supplying some 3000 c.m.h. to the region, as compared to a peak demand of 13000 c.m.h.. The local
groundwater sources are limited by a safe yield which is estimated at 35 MCM and the limited capacity of 20 local wells which are capable of producing a total of 5000 c.m.h. The national hydrological service was involved in estimating the safe yield.

c. The existing pipelines and pumping stations limit the conveying capacities in a part of the links in the system.

Question 5

The existing water supply systems have been designed partwise. The introduction of O.R. and systems engineering has been accompanied by a long dispute, an end to which was put by the final report only. Along the work itself there was an argument of the preferring of a "snapshot model" which deals with the hydraulic variables in greater detail, or a "time expansion" model which deals also with long term expansion and economical preferences along the time axis. Finally a "time expansion model" has been preferred and post factum examined more deeply by the means of a "snapshot model" at two decisive time points.

3. Planning Stage 2: Data Collection & Processing

Question 6

Annual, peak and low consumption data have been collected for the past years from "Mekorot" company data base. "Mekorot" is the only water supplier in the region. The data are specified for the three main consumer sectors in each pressure zone.

The future projection technique was different for each sector:

Domestic future consumption is based on a population growth estimate for each town in accordance with regional and municipal master plans. The living standard growth factor has been taken into consideration as a slow growth rate in the per capita use, typical for each town according to its size and present standard of services. Peak month requirements for the future are somewhat higher than the existing as a safety factor.

Industrial future consumption is based on existing development scenarios and their specific quality, quantity and time distribution requirements.

Agricultural future consumption is based on existing development schemes, which include the growth of sewage availability. Existing agriculture will carry on with the existing annual and peak month allocations. New villages will be based on a basic freshwater allocation (0.7MCM) and the rest will be supplied from reclaimed sewage and saline water sources.

The estimate of existing capacity was based on the maximum recorded flows and not on rated capacities.

The hydrologic constraints were a result of a regional model-aided geohydrologic study.

Question 7. Yes

Question 8. Yes

Question 9. No

Question 10. No

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11

Two systems engineers and one programmer worked on the formulation of a numerical optimization screening model, which included all apparently possible resources and links in the network. The MPSX L.P. Solver aided by a Matrix Generator and report writer was used on an IBM 370/158 computer. The total manpower required is estimated at 12 man-months. With the gain of
experience and the improvement of I.O. auxiliary programs the modeling phase has been considerably shortened.

**Question 12**

The project was initiated and financed by the national water planning and allocating authorities, i.e. the water commissioner and "Mekorot" Company. This project was part of a national W.R. systems analysis.

**Question 13**

The consumers and water authorities took part in the data collection stage. The final solution was not accepted by part of the consumers who felt neglected as most of the development was for parts of the system far distance from them. However a comprehensive examination shows the contribution of the plan to the well being and amenity of the majority of the population.

**Question 14**

The main alternatives of the plan are: I. The division of supply between the various sources and its seasonal and long term variations; II. The flow in links of the network; III. The trade off was between the intensive development of the southern or the northern branch of the main system, and between the strengthening of the connection to the national system or the development of local groundwater resources; IV. The sequencing of development; V. The trade-off between pipe diameter and booster-pump capacities. A large number of alternatives had therefore to be examined. Indeed in the propagation towards the optimal solution the L.P. model searches through a large number of feasible solutions which are all inferior "alternatives". Every iteration in the solution process is a detailed inferior solution in terms of economic efficiency. To justify the chosen solution it is possible to exhibit some of these inferior alternatives.

**Question 15**

The decision-making process associated with the planning was in four levels: (a) The planners level, (b) A professional technical steering committee checked engineering issues and examined the impacts on local and other W.R. systems, (c) A higher level steering committee of the National Water Commissioner's Office which dealt with regional and overall impacts on the W.R. and other systems; the public delegates also took part in that committee, (d) A statutory planning committee of the Water Commissioner composed of delegates from public agencies and consumer sector representatives. The conflicts arose mainly on the development and operation of the sources and conveying systems. Most of the resolutions were achieved in the technical level and confirmed afterwards on the higher levels.

**Question 16.**

**Imposed constraints:**

a. The existing system had to be taken into consideration though not necessarily be exploited in full capacity.

b. The sources' potential was based on prior investigations. Sensitivity tests have been made to the annual safe yield. These constraints were imposed by the G.W. hydrological experts of both Tahal and the Water Commissioner.

c. Forecast demands had to be satisfied. The scope of future development of irrigation areas was discussed with the agricultural planning agencies.

d. Quality constraints could not be relaxed. For a part of the consumers they seemed not reasonable, mainly some types of industry which demanded the best quality available.

**Question 17**

a. A long-term development/operation development/operation model has
model has been developed in Tahal Water Planning for Israel, for the analysis of regional W.R. systems. The model is based on the L.P. technique for the optimization of the development and operation of regional W.R. systems.

b. A hydraulic network solver has been used in parallel for the refinement of the solution and hydraulic dimensioning. The model is a simulator analyzing a "snapshot picture" for a given set of data. The translation of the overall development/operation scheme into a detailed plan for each of the development stages requires repetitive application of this model for each stage and for each season.

The network solver is based on the Newton-Raphson technique and has been developed and programmed in "Mekoroth" Water Supply and Development Company, Israel.

Question 18

Both models have been tested on historical data, and turned out to operate, however not reaching the same optimal solution.

Question 19

The selection of the final plan has been discussed by the technical committee, as well as by the steering committee in which both the authorities and the public took part. The final plan has also been presented in consumers' conferences, which finally confirmed it.

Question 20

There was an interdisciplinary planning effort, but the mix between W.R. planners and other kinds of planners was not appropriate. National planners agencies supplied data, part of which were "in the making" or of low reliability. The involvement of the national general planning authorities (Ministry of Interior) in the local W.R. system planning is not strong enough.

5. Planning Stage 4: Development of Final Project Specifications

Question 21

Based on the MPSX system for the solution of L.P. models, a rather sophisticated general model for the long-term analysis of regional W.R. systems has been developed in the last years. The model called "Tekuma" (L.P. for W.R. systems) is composed of a matrix generator and a report writer combined with the conventional MPSX system. It serves today as an operative instrument for the long-term planning of regional W.R. systems. This regional multi-sector, multi-seasonal, multi-period, multi-state, multi-quality model is an outcome of three main efforts in the mid-seventies:

a. A national multi-regional, multi-sector, multi-seasonal single period L.P. model (Chayat & Vanunu - Tahal, 1975), which combines the optimization of both the agricultural production plan and the operation of national and regional W.R. and supply systems.

b. A national multi-sector, multi-period, multi-state, D.P. model (Schwarz, 1980).

c. A regional multi-objective, multi-sector, multi-seasonal, multi-period L.P. model (Alkan & Shamir - Technion, Haifa, 1977), which analyzes the long term development and operation of a regional W.R. system. This work dealt with the Eastern Negev as well, but covered a larger area and a wider scope of national goals, such as employment and environmental impacts.

The general purpose "Tekuma" model (Schwarz, Alkan et al. - Tahal, 1981) was developed in the late seventies and has been used since then for three regions in Israel - Eastern Negev, Western Negev and Arava Valley. At present, such a model is used for planning the long term national W.R. development and operation, as well
as the planning of the central part of Israel.

Question 22

Unit costs are included in the model. Total costs are presented as part of the results.

Question 23

No specific risk analysis was carried out. However, the design of reservoirs was based on short breakdown periods of the electricity supply to pumping stations.

Question 24

Preferred solutions were found for different values of the unknown parameters. The most likely value was finally selected. The trade-offs could be examined by shadow prices of the various constraints.

The optimal plan suggests the strengthening of the northern, poorly developed arm and the closing of the regional main system into a loop. To convince the professional bodies and above all the southern part consumers, a number of economically inferior solutions were presented.

The suggested development scheme for the "eighties" consists of investments and items listed in the table enclosed hereafter.

Question 25

The project encourages the local solution of environmental nuisances by the enlargement of areas irrigated by sewage effluents. The extensive reuse of sewage effluents for irrigation in the Beersheva valley does not create till this day any severe damages or disturbances to the public, and on the other hand adds to the area a large green oasis in the desert. The development of two national industry centers in the Eastern Negev enables the transfer of all heavily polluting industries from the central part of the country to the desert. The purpose of this transfer, in addition to the prevention of direct nuisances, is the protection of the main fresh groundwater sources. The southern part of the Eastern Negev is non aquiferic and sparsely inhabited and thus suitable for industries.

Question 26

The introduction of an O.R. device for planning purposes was somewhat problematic. The "black box" was not always rightly appreciated and accepted by all people involved. Prior to the regional analysis the planning and operation of the region was completely separate for the northern, groundwater fed Beer Sheva region, and for the southern Har Hanagev region, fed by the national system.

The integrated regional approach from the start, and the solution which contradicted the "separatistic" approach, were rather difficult to bring through both professional and steering committees. "Conventional" design and direct comparison of alternatives were supplemented.

Question 27

The process of approval was by the two level steering committees and finally by a statutory planning committee of the water commissioner. This is usually a tedious process which requires not less than one year after completing the plan. The rapidly increasing demands pressed the decision-makers to accept a plan and execute within a shorter schedule. After having succeeded in convincing that the optimal plan is also advantageous in the efficient phasing of the execution, pipes have been ordered in the factory shortly after.

Question 28

The planning activities have been coordinated continuously with the national financial referee in
the steering committee. National budgets have been promised for the various system development stages in full accordance with the suggested plan.

**Question 29**

Post planning evaluation was concerned mainly with sensitivity analysis to unknown design parameters such as: safe yield of the aquifer; capacity of wells; peak month demand; availability of the national system; etc.

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### EASTERN NEGEV WATER-SUPPLY SYSTEM DEVELOPMENT SCHEME (NIV., 1980)

<table>
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<th>Stage</th>
<th>Total Investment ($)</th>
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<td>B. Sheva, M.</td>
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<td>Tlifar S. 5000</td>
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6. **Planning Stage 5. Project Design**

The design phase was carried out separately by another engineering team. The detailed design of pipeline layouts and pumping stations followed the general plan resulting from the O.R. analysis.
East Negev Fresh Water Supply System

Daily Flow Schemes for Years 1985, 1990

1985  1990
Summer Average Daily Quantities (Cu.M.)
Winter
LONG TERM INTEGRATED PLANNING OF THE
DRINKING WATER SUPPLY IN THE PROVINCE OF
SOUTH HOLLAND (THE NETHERLANDS): IODZH

By

A.H.M. Bresser,
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Project Leader of the Second Stage of the IODZH Study

1. Introduction

Water supply in the Province of South Holland (The Netherlands) is presently dealt with by 30 water companies. The 1980 demand for piped water amounts to 250 x 10 m /a. Future demand (2010) will be between 270 and 420 x 10 m /a with a best estimate of about 340 x 10 m /a. The present water supply system consists of 8 groundwater pumping stations, 16 pumping stations of bankfiltrated water, 3 for infiltrated surface water by means of ponds and 3 purification plants for reservoir water. It will be necessary to enlarge parts of the system. Water companies have made requests for licenses to enlarge, e.g. the infiltration capacity in the dune area along the coast of the North Sea. This area is a nature reserve of high quality and is also partly used for extensive recreation. Possible alternatives for the supply are the use of excess capacity in reservoirs and purification plants, enlarging the use of bankfiltrated water or a rather new technique for infiltration by means of injection. Since conservation of nature and recreation interests both demand a decrease of infiltration in the dune area also, alternatives with a reduced infiltration capacity have been studied.

The study has been centered around and guided by an extensive system study using both simulation and optimization as techniques (1). Supporting studies have been undertaken in the fields of groundwater hydrology (especially in the dune area and for bankfiltration), dose effect relations between water supply and nature, between recreation and nature and between water supply and recreation, water quality, reliability of the supply system and costs. Surveys have been made of the present situation of nature, recreation and water supply.

At the final stage of the study most of the results of the substudies have been incorporated within the simulation model.

In the Netherlands planning of the water supply consists of three forms. The long term planning (30 years period) for the country as a whole is done at the central government. Medium term planning (10 years period) is a combined task of regional government (provinces) and the watercompanies. Short term planning is done by watercompanies. The IODZH-study is a combination of long term and medium term planning on a regional scale, so both the central government and the provincial government were involved and took part in the Steering Committee.

The study has been carried out in two stages. The first was ended in August 1981 with an Interim Report (2). With this report the study focussed on the central part of the problem, cut back both in the region under study and alternatives considered and went into more detail for the remaining part of the problem. The final stage ended in
August 1983 with the Final Report (3) presenting an overview of the study as a whole, describing briefly the methods used and focussing on conclusions regarding the possible solutions for the development of the water supply, recreation in the dune area and nature preservation (regeneration included).

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1

The system involved is influenced by two planning procedures: on water supply and on physical planning. The central government sets up a long term planning scheme ("Structuurschema") which is worked out in 10-year plans for the water supply and in specific projects such as pumping stations and purification plants. The long term planning scheme is also worked out in physical plans for regions and destination plans for certain areas.

Along both lines planning is a continuous process with licenses for actually building projects. Licenses have to fit in the long term schemes which mostly provide for boundary conditions. Along both lines a number of plans and requests for licenses came up with respect to the same area and system. In order to provide for an integrated solution of the complicated problem for water supply, recreation and nature, the study has been initiated by the former National Institute for Water Supply and appointed Ministries involved and Provincial Government of South Holland.

Question 2

In the study a division had been made between governmental planning and the technical planning procedures. The first has been dealt with by the Steering Committee whose members are top-administrators of central and provincial government. The technical part of the planning (i.e. the study itself) has been carried out by 7 research institutes under supervision of RID (now RIVM). The institutes are: Delft Hydraulics Laboratory, National Institute for Water Supply, National Institute for Nature Studies, Institute for Environmental Studies and Health TNO, Research Institute for Water Supply KIWA, the Provincial Physical Planning Department and the Centre for Environment Studies of the University of Leiden. The people carrying out the study almost all had an academic degree. The disciplines varied from mathematicians and engineers to biologists and experts on recreational behaviour. The objectives of the study have been formulated in the first stage of the study and were taken from publicly accepted planning procedures. The Interim Report which contains the objectives and the first screening of alternatives appeared in 1981 and was discussed in public, as the Final Report, issued in Summer 1984.

Question 3

The most important criterion for initiating the study was that until that time all attempts to reach agreement on the use of the dune area had failed, while within a limited number of years actual decisions had to be taken on this subject.

Question 4

Constraints posed on the study were: limited to the province of South Holland, no direct involvement of the interest groups (i.e. watercompanies, environmentalists action groups), use only existing data. These constraints were posed by the governing bodies. The first constraint (areal) did not cause serious problems although slight deviations from it were made which were acceptable. The second constraint (no watercompanies or
interest groups involved) caused many more problems. It was discussed extensively and a compromise between the project directors and the project team was found: technical data and discussions on technical matters with the interest parties were allowed, thus providing a better connection between the study and reality. Still, even after finishing the study, this constraint poses serious problems because implementation of proposed solutions needs cooperation between administration and water companies. The third constraint also caused severe problems because data on the present state of nature in the dune area was insufficient to make predictions on possible effects due to alterations in the infiltration system. This has been solved at the cost of about a year extra time and several man years extra labour.

Question 5

In the system analysis part of the study at first there was an extensive discussion on the methods to be used: optimization or simulation. Both methods were adopted with emphasis on the simulation. This decision was reached on a technical level and was approved by the Steering Committee after a briefing by the study team. On methods to be used in substudies the study team decided primarily, and made a proposition for the Steering Committee for approval of financial aspects and manpower. On some occasions the Steering Committee changed proposals, in extent or content, mostly because of financial reasons.

3. Planning Stage 2: Data Collection

Question 6

The substudies made use of their own databases and provided data for the system study and for other substudies. The hydrological study used observations of levels of phreatic groundwater and of heads in semi confined groundwater (annual averages have been used). The validation of the models was done with data of three years. Hydrogeological data were derived from pumping tests and various other sources. Changes in hydrology, calculated with the models as annual averages in a steady state for a number of situations, are inputs for effect calculation. Travel times of water to drains and wells were also calculated providing data for protection zones and forming input for physical planning and for the recreation study. Input data for the nature studies are surveys of plants and vegetation over the province as a whole (this had been carried out earlier by the Provincial Physical Planning Department except for the dune area: that survey was part of the study). Also numbers of breeding pairs of birds, gathered continuously by bird watching groups, were used. For recreation, input data were counts of visitors in certain areas at several times, and interviews. Water quality of the sources of groundwater was measured once in the study as a check on available information (annual sampling). Water quality of rivers is measured continuously at several points along the rivers Rhine and Meuse for a long period. The data of the period 1975-1980 (incl.) have been used. For reliability, data on failures are scarce so mostly estimates have been made. The prediction on future demands were based upon demographical data from the Central Bureau of the Census and the Provincial Physical Planning Department. Data on industrial development were obtained from the National Physical Planning Department. Data on specific water consumption were obtained from an earlier study of the National Institute for Water Supply. All water consumption data are yearly averages. Water consumption in the Westland horticulture area has been calculated on the basis of data from the horticulture research institute and vary within a year. The system study uses figures of the present situation (lay-out, capacities, cost figures, etc.) of the supply system as obtained from the water companies.
Not only existing data have been used. Surveys of nature value have been made (counting plants and vegetation types over 600 hectares of dune area). Recreation activity was counted. Analyses of water samples from groundwater pumping stations were made. Dose-effect relations have been established from literature and from other research. In other fields the inventory of already existing data took much effort. Forecasts for the demand and for water quality in groundwater and rivers were inputs in the models and had to be generated with the aid of historical data.

Formal OR techniques were not used to determine the data collection scheme. Practical considerations dominated this aspect, aided by some analysis. The water resources management models used are deterministic. The available and obtainable data did seldom allow for a statistical approach. Data collection on the present situation for nature posed a problem. Several possible ways of calculating effects of vegetation were available, all requiring different data sets. Since the survey of the dune area had to be made in an early stage of the study the method had to be decided upon. A small computer programme (simulation) was used to compare the different methods and to decide on the way in which the survey had to be carried out.

No specific programme has been set up to assess the availability of the data bases used. But the data on the survey of the nature values in the dunes had to fit in a data base of nature values in the rest of the province which already existed. The programmes for processing these data had to be altered for this purpose.

Analysis of historical data on water quality of the rivers has been done with multiple regression analysis for a large number of parameters using a standard programme (4). Experts' views were used on several occasions as data, sometimes as dose-effect relations, sometimes as weighting factors in combining criteria. These views were solicited by interviews, sometimes making use of the Saaty-De Graan method (5).

4. Planning Stage 3: Formulation and Screening of Project Alternatives

In this particular case the study compared alternatives in two stages: screening based on rough comparison of alternatives, leaving out obvious bad ones, and then further detailing of remaining alternatives and careful comparison and judging of these against objectives. The questions in this chapter will be answered for the first stage. The development of methods to be used in both stages of the planning process was part of this first stage of the study and resources used cannot simply be divided into resources for the planning and for development of methods. So the sum will be presented.

It took about two years, 15 manyears and 1.5 million guilders (about $600,000) to complete the first stage of the study. By that time much had already been prepared for the final stage. Several computers had been used. The simulation model version 1 was run at the computer of Delft Hydraulic Laboratory (in Dynamo III). The second version, also in Dynamo III, was on the computer of IBM Zoetermeer. The third version in Fortran was run on the computer of ENR in Petten. Both DHL and RID had a direct line to this machine.
The optimization model also ran on the ENR computer with the PDP-minicomputer of RID as terminal. The large hydrological models ran in Petten, while the smaller ones ran on the PDP at RID. The data on nature were processed on the computer of the Provincial Planning Department. The total effort had been spread over working teams whose leaders participated in a coordination team under the project leader.

Question 12

Institutional support was provided by the Steering Committee and the Advisory Committee and by a Task Force on Legal and Institutional Aspects. Representatives from the ministries involved and from the province took part in these committees. All along the study decisions had to be made on aspects of finances, screening, sometimes methods to be used, time etc. Most decisions could be taken by the project leader (within the budget and the project programme). Major decisions were taken by the Steering Committee with the advice of the project leader and the Advisory Committee. Some of the intermediate results of the study found their way into provincial policies on water supply after the Interim report had been presented.

Question 13

There was no direct public involvement in the study after the start and before the Interim report had been presented. The Interim report was distributed widely and discussed in a public meeting.

Question 14

In principle all projects for drinking water supply which were technically feasible have been studied to some extent. Not all combinations of projects have been studied. In an early stage of the study a limited number of connections between supply points and demand nodes were proposed and discussed with the Steering Committee. The Interim report gave a screening of the alternatives. The remaining ones were studied in much more detail in the second stage of the study.

Question 15

Decision makers in this case are the Provincial Government and the two Ministries of Physical Planning, Housing and Environmental Management and of Agriculture and Fishery (recreation and nature preservation included). Civil servants of these bodies form the Steering Committee. Proposals for screening and alternatives were made by the study team and discussed in the Steering Committee. The suggestions for screening were supported by trade-offs between criteria such as costs, drinking water quality and damage to nature and by alternative combinations of projects with the effects of all criteria.

Question 16

The constraints were already discussed at question 4. Sometimes they could be relaxed in discussion with the Steering Committee.

Question 17

The model for simulation of the development of the water supply system (DRISIM) was developed by DHL and RID. It was first written in DYNAMO, a try as made in ACSL and it was finally rewritten in FORTRAN. The optimization model was written around the APEX standard LP-routine available at ENR in Petten. The decision models of Saaty-de Graan had been developed earlier at RID. The hydrological studies made use of standard models available and mostly developed by RID (TRISE, MESH). Processing of nature values has been done by the Provincial Planning Department (PPD) with its own existing programs. For the calculation of effects on vegetation and birds the DHL together with the PPD and RID developed an algorithm on the computer of PPD.
The multiple correlation of water quality was performed with the COMPAN- program, developed earlier at RID.

Question 18

The simulation and optimization model have been tested with the historical development of the water supply system. Calculation of effects could seldom be tested because all available data on effects of historical developments of the system were used to determine dose-effect relations. The effect calculations therefore did not have an absolute meaning but have only been used in a comparative way in the first phase of the study. The hydrological models had been tested already (standard programs). The models were calibrated with data on heads and groundwater tables and with historical situations.

Question 19

In this stage of the study the "technical" experts (= study team) made very specific proposals for screening of alternatives. The Steering Committee discussed the proposals, adjusted them when necessary (slightly) and presented the Interim report to the ministers involved and the Provincial Government. Several different advisory committees on physical planning and environment, the water companies, action groups and other interested people were asked to comment on the report. A public presentation has been held. Governmental decision-makers adopted this intermediate result and agreed on the second stage of the study.

Question 20

Yes, it certainly has been an interdisciplinary planning effort, and the mix was rather appropriate. The study team suggested the incorporation of an institutional substudy, but the Steering Committee did not allow for this. The most disappointing thing has been that no water companies were allowed to take actual part in the planning process.

The combination of biologists and technicians proved to be very worthwhile for both. Understanding of each other grew with the study especially by the intensive discussions in the study team. This resulted in solutions for the development of the water supply system, recreation and nature preservation that can be named harmonious, despite great conflicts about the same matter in the past. So a joint planning procedure seems to be much better than only calculating effects of plans after the design of a limited number of alternatives (which is the case in environmental impact assessment).

5. Planning Stage 4: Development of Final Project Specifications

In this chapter only the final stage of the study will be discussed, i.e. further detailing the remaining alternatives and comparing them in terms of the objectives, analysis of the field of possible solutions and drawing conclusions from the analysis.

Question 21

OR methods have been used as in planning stage 3 (see chapter 4, questions 11 and 17). The optimization model was not used to define an optimal solution but as a screening procedure to define obvious inferior solutions. The simulation model was used to find harmonious solutions. Most of the modelling has been done by DHL and RID. Of course parts of the model were derived from literature, but the literature itself was not very useful. The system study team had advisors at its disposal (Prof. U. Shamir and Dr. W. Wils). In discussions and exercises different methods have been explored. The main part of the system study was the simulation model. This has been rewritten three times in different computer languages. Dynamo III was the first one, but the implementation of Fortran subroutines in Dynamo was, at that moment and on the computer that was
was used, not possible. ACSL was the second one, but the training of the people with this language was insufficient, so finally the model was written completely in Fortran. This model was more or less optimized, reducing the costs for a run by a factor of about 20. The final version of DRISIM is a very useful one and easy to run. It has been used, with alterations for specific uses, since then in several other studies at DHL. So the model can easily be made to fit the problem, and except from the necessary schematization of the supply system the problem does not have to be adjusted to fit the model. The simulation model grew with the study. It is not possible to assess the time used to construct the model. Constructing, reconstructing and running the model were part of the central role of the system study in the project as a whole, guiding substudies and gradually reaching conclusions.

**Question 22**

No specific cost-benefit analysis has been made. Costs were, together with a number of other criteria, an objective to be minimized in both the models and in the study as a whole.

The costs of the study itself are rather high. But at the start of the study a political impasse had been reached which had to be broken. It is not be expected that a study of this magnitude will be carried out again. Parts of the study might have been done at less costs, with the same impact on the conclusions.

**Question 23**

Risk analysis of the system under study formed part of the simulation model. Reliability of the supply system was one of the criteria the decision-makers decided upon, and sought to obtain information about. Although data on failures in supply systems are scarce and a statistical approach shows great uncertainties, the analysis of this item was rather successful. Weak spots in the system could be identified. A trade-off between costs and reliability is possible to a certain extent. Discussions on this item are continuing.

**Questions 24/25**

The simulation model generates alternatives for the development of the water supply system and calculates the effects on a number of objectives (nature included). An alternative originates from a strategy, a scenario and a set of technical assumptions. A strategy in this case is a set of maximum capacities for all projects and pipelines in the system and a prescript of the order in which projects supply water to each of the demand nodes. A scenario is a set of assumptions on developments which are outside the system, (such as the economic development or the energy price). A large number of alternatives has been generated, each with all the effects calculated too. The alternatives are points in a continuum. The main variables in the strategies were the amount of surface infiltration in the dunes and the amount of deep infiltration. When using these two variables as axes, the alternatives can be put in a figure where lines of equal effects can be drawn for each of the criteria (see Annex I). Eleven objectives in all were considered:
(1) Vegetation: changes in area covered by vegetation types; weighted
(2) Landscape: changes in the value of landscape (area times weight)
(3) Birds: changes in numbers of breeding pairs times the value of types of birds
(4) Ecosystem: disturbances at various levels within ecosystems (area times the intensity) times the importance of a level within the system times the value of the ecosystem
(5) Water quality: the weighted average of 12 parameters (with standard considered)
(6) Public health: the judgement of experts of source-purification systems
(7) Security of production: the judgement of experts of source-purification systems
(8) Reliability of supply: the calculated non-deliverance as promillage of the supply
(9) Production costs: in cents per m³ delivered at the planning horizon (2010)
(10) Present value of total costs: total over the system in the planning period
(11) Present value of investments: total over the system in the planning period

Vegetation, costs and water quality were considered the "leading" objectives. This does not mean that the other objectives are unimportant, but rather that these three are, under the present circumstances, the ones which most determine the best compromise solution.

For each of the criteria five classes have been identified varying from A (= in contradiction with the goals for the objective) to E (= completely in line with the goals). The classes have been derived from policy documents and in discussion with the Steering Committee. Combination of the figures for each criterion showed an area with alternatives where no objective was contradicted (except landscape). These solutions were called reasonably good solutions. Within this area a more limited number of so called harmonious solutions could be identified where the scores on the major objectives (vegetation, costs, water quality) were positive (annex II). Except from
infiltration, water can be supplied from bank filtration or from reservoirs. In the alternatives of annex I and II the order in which these projects are used was standard.

Different strategies have been investigated. Annex Ill shows some results in objective space, the deciding objectives being costs and vegetation as can be derived from the annexes I and II. Formulation of conclusions from this analysis was done in discussion with the Steering Committee. The graphical presentation (together with tables) proved to be very useful in the discussions. The optimization model was not used in this phase despite the built-in possibility of multi-objective optimization because the decision process itself was important and no weights could be established beforehand. Besides the results of this model were too aggregate. The direct discussions between analysts and Steering Committee proved to be very successful. Graphics are very useful in this discussion. The analysis has been supported by an extensive sensitivity analysis on variables in strategies, scenarios and technical data set. One of the methods used in this is with META models (6). This provided information on the necessary width of the classes used and the discrimination between alternatives. It also provided a sound basis for discussions with the Steering Committee.

Question 26

The decision-makers accepted the report as a base for future policies. They added institutional and legal "information" to it. The conclusions of the study are - among others - suggestions for the capacities of projects that should be licensed at a maximum. Decisions on the licenses have not been taken yet. (January 1984). The study did not end up with an "optimal" solution. There is no such thing as "the" optimal solution in this case.

Questions 27/28

The design of a final plan was not part of this study.

Question 29

Not yet (January 1984)

6. Planning Stage 5: Project Design

The design of supply pipes and projects was not part of the job. Watercompanies themselves design parts of the supply system within the constraints of licenses and funds. The simulation model DRISIM is used presently to the further design of parts of this system.

Acknowledgement

The start of the project and the first stage of the study have been guided by the first project leader Mr. F. Langeweg of RID. Without his driving power the study would probably have ended at its beginning with a lot of confusion between disciplines. The study has been supported by the Steering Committee with chairman Mr. P. Verkerk and secretary Dr. H. de Boois. The positive approach of this committee to the problems both in management and in contents largely contributed to the success.


Literature


5) Graan, J.G. de, 1978 Some extensions to the decision model of Saaty National Institute for Water Supply (RID)

ANNEX 1A  Lines of equal effects on objectives for entire alternatives
(for legends see Annex 1B)

- Effects on vegetation
- Effects on landscape
- Effects on birds
- Effects on water quality
- Effects on entire ecosystems
- Effects on public health
ANNEX 1B  Lines of equal effects on objectives for entire alternatives

- Security of production
- Production costs
- Present value of total costs
- Reliability of the supply
- Present value of investments

Legends:

A = in conflict with the objective
B = some conflicting points
C = neutral or indifferent
D = some positive points
E = in full accordance with the objective

Capacities in millions of m³/a
ANNEX 2  Selection of harmonious alternatives

Legend:
- Harmonious solutions
- Reasonably good solutions

Capacity of deep infiltration (in millions of m³/a)
Capacity of surface infiltration (in millions of m³/a)
ANNEX 3  Comparison of alternative strategies on costs and vegetation effects

Alternative 7
Capacity surface infiltration = 50 million m³/a
Capacity deep infiltration = 40 million m³/a

Additional strategies
- no deep infiltration; standard strategy
- standard strategy + deep infiltration
- use of reservoirs + existing plants
- use of bankfiltration
- new purification plant

Present value of total costs (million guilders)
POST EVALUATION OF THE PLANNING PROCESS
IN THE MAUMEE RIVER BASIN LEVEL-B STUDY

By

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1. Introduction

A hierarchical-multiobjective modeling and optimization effort has been applied to Level-B planning in the Maumee River Basin. The principles and standards for water and related land resource planning prepared by the Water Resources Council and adopted by Congress on 10 September 1973 identify two major objectives in such planning:

1. To enhance national economic development by increasing the value of the Nation's output of goods and services, and improving national economic efficiency.

2. To enhance the quality of the environment by the management, conservation, preservation, creation, restoration, or improvement of the quality of certain natural and cultural resources and ecological systems.

The overall purpose of water and land resource planning is to promote the quality of life by reflecting society's preferences for attaining the objectives defined above. The three levels of study, known as Levels A, B, and C, are aimed at identifying water and land problems, developing plans which are responsive to the above objectives, and finally, implementing these plans.

The Level-B study in the Maumee River Basin was structured to identify and evaluate all of the major water-related land resources problems. It considered and evaluated all of the measures that may resolve these problems and offered both an immediate action and long-range action plan for implementation by various levels of government. Programs were recommended to fill data and research gaps. In addition, a coordinated approach to needed detailed studies of management and structural programs was identified for implementation at all levels of government. The Maumee study area consisted of approximately 5,700,000 acres of land and 40,000 acres of
water surface (see Map). More than half of the latter is the surface of Maumee Bay. Much of the land, nearly level or gently sloping, is in agricultural use. Because the soil has a slow permeability rate, natural drainage problems exist throughout the basin.

Much of the basin's area is prime agricultural land developed through drainage of the Great Black Swamp. However, there are also substantial urban concentrations centered about the cities of Toledo, Lima, and Fort Wayne. Already this represents an emerging conflict over optimal allocation of land use: whether urban expansion or agricultural production should have priority in the future. The most serious issue at present is that of water quality. Point sources, municipal and industrial, and nonpoint sources, urban and agricultural runoff, both contribute heavily to waste loads. Sedimentation due to erosion is a problem throughout the basin, which is amplified through deposits at the Maumee Bay. Shoreline flooding remains a troublesome problem, and navigational issues are quite important to the economy of the region. Finally, quality of life considerations come into play in the areas of recreation, fish and wildlife preservation, and environmental conservation.

Related problems for purposes of the Maumee study have been isolated and are referred to under the categories of land resource management, erosion and sedimentation, water quality, fishery resources, wildlife and hunting, outdoor recreation, flooding, and water supply.

Planning for the area involved both political and hydrologic boundaries. The entire three-state Maumee River Basin, including the entire drainage area of Maumee Bay, was considered, as were the state and county boundaries encompassing the drainage area. River basins cross state and country lines and are governed by a broad array of political institutions. To minimize complexities associated with crossing political boundaries, the Maumee study area was divided into five subareas, each bounded by county lines and each lying within a single state. A sixth planning subarea, Maumee Bay, was unique in that it is composed entirely of water. Level-B planning studies attempt to coordinate and involve all levels and units of government responsible for water resources in the area studied. Accordingly, the Maumee Level-B Study involved state, regional, local, and federal agencies.

The ultimate objective was to formulate a comprehensive management plan which would alleviate the serious problem of the basin. The purpose of this study was to investigate some of these critical areas which must be faced in the development of such a plan. In particular are two broad areas of consideration: (1) technical problems, including the identification of goals and decision variables, and the measurement of parameters and performance; (2) institutional problems, including area of influence and responsibility, and availability of resources.

2. Planning State 1: Project Initiation and Preliminary Planning

Question 1

Yes. The Maumee River Basin Level-B Study initiated by the Great Lakes Basin Commission was an effort to set up a comprehensive 15-year (1976-1990) program (plan) to deal with the major problems in the basin, such as water quality and land use (including soil erosion, recreational facilities, preservation of wildlife habitat, flood control, etc.). The goal of this research was to develop a management framework for the Maumee River Basin's water and land resources problems within the guidelines of the Water Resources Council's Principles and Standards.
At the time the Maumee River Basin Study was started, a level-A long-term planning programme was underway and nearing completion. The Level-A Study covered the entire Great Lakes region and encompassed portions of eight Great Lakes states, all of the U.S. water area of the lakes, and the St. Lawrence River as far as the international boundary. It was contemplated that the more involved, complicated, and immediate problem areas within the entire Great Lakes basin would be treated with individual level-B studies of the Maumee type. The most urgent problems in the Great Lakes basin were considered by the Great Lakes Basin Commission to be the Maumee River basin, which provided the subject of the first level-B study initiated after the Level-A Study of the Great Lakes Basin as a whole.

**Question 2**

The Great Lakes Basin Commission formed a Planning Board, with members from the following state and federal government agencies: the Indiana Department of Natural Resources, the Michigan Department of Natural Resources, the Ohio Environmental Protection Agency, the U.S. Department of Agriculture, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the U.S. Department of the Interior, the Great Lakes Basin Commission, and the Maumee Citizen's Advisory Committee (CAC).

In addition to the relatively highly skilled personnel in the state and federal agencies, the Great Lakes Basin Commission's planning staff foresaw the possibility of testing innovative planning processes in the development of the Maumee River Basin plan. One of these processes was the surrogate worth trade-off method of hierarchical planning that was being developed at that time by Dr. Yacov Haimes of Case Western Reserve University and Dr. Warren Hall. Dr. Haimes was agreeable to the idea of cooperating with the Commission's planning, and formed a research team task with the title: A Multiobjective Analysis in the Maumee River Basin - A Case Study on Level-B Planning. This team was composed of, in addition to Dr. Haimes as the principal investigator, three full-time research assistants and one technical secretary. Also involved in this research project, on a part-time basis, were one post-doctoral fellow and four other research assistants.

The public was involved in the formulation of project objectives. In fact, the Citizens' Advisory Committee was established in order to represent the public and interested citizens' organizations in Indiana, Michigan, and Ohio. In response to the major problems and concerns within the basin, the CAC identified eight major goals for the Level-B plan.

**Question 3**

From the beginning it was clear that limits would be set on this project in terms of the funds granted (1.5 million dollars) and the time available (3 years). Other factors that influenced the nature of the study were the structure of the agencies conducting the study, the neutrality of the commission staff, and the responsibility and interest of the several states in the study.

The nationwide criteria for level-B studies required a review of severe problems and the development of a series of alternative solutions. The alternative solutions supported three different goals: national economic development, environmental quality, and a mixed approach.

The national criteria for level-B studies also required that these studies do not normally develop specific projects for construction but should instead present a program for the basinwide resolution of problems. Consequently, specific project
design was not undertaken in the Maumee River Basin Level-B Study. The normal decision criteria for project development (such as that it presents a favorable benefit/cost ratio, that there is no less expensive way to achieve the same benefit, that each part of the project is incrementally justified, and that the project will benefit the public as a whole rather than just a small segment of the population) were not rigidly employed.

Question 4

Because the Maumee River Basin Level-B Study was constrained by time and funding as well as by the use of existing data and conclusions of past and ongoing studies, not all of the Goals and Objectives established by the Citizens' Advisory Committee could be met by this study. More specifically, the limiting use of existing data was imposed by the Water Resources Council in their "New Approaches to Level-B Planning." This, together with a funding cut (to 1.5 million dollars) and time cut (3 years) presented problems throughout the entire study period. Moreover, the National Water Resources Council's Principles and Standards for Water and Related Land Resources Planning caused more confusion rather than guidance. Each agency involved in the study had various interpretations and explanations of the Principles and Standards. Because these interpretations expanded the range of suggested action, additional constraints seemed to exist in that the members of the Great Lakes Basin Commission objected to consideration of the extreme alternatives which would produce either a totally economic development-oriented plan or a totally environmental preservation and improvement plan, since these extremes would be unacceptable to certain segments of the public and might be politically damaging. Consequently, the staff and the Planning Board were directed to eliminate the more drastic extremes first designed and consider those closer to a midpoint. The national laws in effect at this time placed primary water quality responsibility in the hands of the state, with the federal government having regulatory responsibility. The study needed a systems approach to water quality and a water quality plan for the entire basin. The states were not equipped to prepare such a plan. The federal government refused to undertake it since they considered this to be a state responsibility and interpreted federal regulations to allow only one approach to water quality improvement. Consequently, the Planning Board could not use a desirable systems approach on a quantitative basis that might have led to an optimum solution to the water quality problems in the basin, and they instead selected as a surrogate the arbitrary reduction in silt as an indicator of environmental quality within the river. This is a relatively correct but limited representation. It obviously is not a full treatment of the environmental quality problem. Consequently, the study was inadequate in this respect.

Question 5

No. In addition to discussion concerning environmental quality, the efficacy of the surrogate worth trade-off (SWT) method was initially questioned because of its newness and untested condition. The consultants from Case Western Reserve University presented their method to the Planning Board. The Planning Board was encouraged to support the development of the information needed by the SWT practitioners. Agreement over methods to be used or disputes arising within the Planning Board, between the Planning Board and the technical experts and consultants, or between the Citizens' Advisory Committee and the study committee were resolved by a Steering Committee which represented supervisors of the Planning Board members. The Basin Commissions had the final responsibility for the specific recommendations emanating from the study.
3. Planning Stage 2 - Data Collection and Processing

Question 6

Level-B studies are precluded from collecting data as a specific activity. In most cases where critical data are absent, a minimum data collection effort, within funding and time limitations, is permitted; however, most previous studies had spent more time and money on data collection than on problem resolution, and the Level-B Study was designed to counteract this situation.

The study used the OBERS Series-E projections of national demographic and economic growth. OBERS is an acronym derived from the two federal agencies involved in their preparation: the Bureau of Economic Analysis (U.S. Department of Commerce) and the Economic Research Service (U.S. Department of Agriculture). These two federal agencies are the principal sources of the long-range projects of population and demand for resources used by the United States.

In the mathematical analysis used in the Maumee River Basin Study, the base year data consisted of data from 1974 and 1975, and the 1990 data projection came from OBERS Series-E projections. The physical data used in the study include information on the drainage area, land use and land availability of the basin for agriculture and other land activities, and hydrologic and pollution effluent data for the existing treatment facilities plus their capacities and location. Various agencies were the source of estimated data, such as the effectiveness of recreational development and flooding prevention.

The Corps of Engineers had recently completed a basinwide study of hydrologic characteristics of the basin and their impacts upon flood control. Consequently, no additional hydrologic investigations were conducted.

Social and economic data were supplied by the state and other political subdivisions within the basin.

Question 7

In general, only existing data were used. However, new analyses and displays of existing data were developed. Artificial generation of hydrologic data had been developed by the Corps of Engineers and this information was available to the study. Some measurements were continued during the planning stage, such as water quality measurements, but these had relatively minor effects on project planning.

Question 8a

No

Question 8b

Yes. In particular, the land resources management cost optimization model, which was composed of an agricultural land management practices submodel, a recreational development submodel, a wildlife preservation submodel, and a flood plain acquisition submodel, was restricted to being a linear model because of the incomplete information or data on these related subjects.

It was apparent that a water quality planning model should be developed, taking into consideration contributions from point and non-point sources jointly. In this phase of the research, four pollutant constituents were considered for intensive study. These were sediment, phosphorus from point sources, phosphorus from distributed sources, and the biological oxygen demand (BOD) load from municipal and industrial waste discharges.

However, this is not to imply that other polluting substances are not important. The lack of data and a lack of knowledge of the relationship between the amount of
discharge of these constituents and the resulting level of water quality prevented us from including them in the analysis.

Question 9
No.

Question 10
No.

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11

The resources of time funds and personnel used in the planning process have been discussed in Planning Stage 1. An additional $100,000 was granted by the National Science Foundation and the Office of Water Research and Technology to support the CWRU multiobjective analysis research activity used for the study. Various computing facilities were extensively used to generate and confirm the data needed and to analyze the objective trade-offs finally recommended by the CWRU research team. A UNIVAC 1108 computer was used for the multiobjective analysis.

Question 12

Institutional support was provided by the U.S. Water Resources Council with respect to funding of the project by the federal government. The Council also obtained responses from the federal agency and attempted without success to resolve the problem of the lukewarm cooperation of the U.S. EPA.

The Great Lakes Basin Commission provided substantial additional support to the study by providing specialized help when needed and supplying additional manpower for public relations interaction with the Citizens' Advisory Committee. The states, particularly Ohio, furnished top-level support where needed and also provided input from their regular planning agencies. All needed past records of the states were made available. Local political entities provided cooperative support in furnishing meeting facilities, public notices, and other general support activities. The cooperation was generally adequate. However, more timely input would have been helpful from the federal agencies, particularly those dealing with environmental quality.

The study conducted by the CWRU team was monitored by a carefully selected Advisory Committee consisting of one member from each of the following agencies: (i) the Great Lakes Basin Commission (ii) the U.S. Department of Agriculture, Economic Research Service (iii) the U.S. Geological Survey, Water Resources Division, and (iv) the U.S. Water Resources Council. In addition, the Principal Investigator attended meetings of the Advisory Committee, as did project officers from the National Science Foundation--Research Applied to National Needs Program, and the U.S. Department of the Interior--Office of Water Research and Technology.

Question 13

Citizen involvement played an important role in goal setting, the definition of alternatives, the determination of priorities, and the formulation of the final plans. One mechanism for public participation was the Citizen's Advisory Committee (CAC), a nongovernmental group of thirty private citizens from the three states who worked closely with the government planners in guiding plan development. The preliminary alternative solutions developed in the first phase of the study were reviewed and refined through a series of public workshops held in cities across the basin during October 1974. Following participation in this review and further refinement and agreement by members, the CAC published its Goals Report (March, 1975).
A series of open and information public forums was held in eight cities in January, 1976. The purpose of these forums was to review the Economic Development and Environmental Quality Alternative Plans as starting points for discussion of what citizens would like to see incorporated in the Final Plan. At the time of the forums, written comments on the alternative plans were also solicited, and a questionnaire was mailed to everyone on the Maumee Study mailing list. The purpose of the questionnaire was to quantify public choices and concerns in a way that would assist the planning process.

The questionnaire, the summaries of small work-group discussions that took place during the forums, and the reviews and preferences stated by the CAC were all used in defining the Final Plan and in assigning relative public priorities to proposed programs. The Final Plan thus reflects public preferences for implementing programs and addressing the water and related land-resource needs of the Maumee Basin.

Question 14

The Maumee Citizen's Advisory Committee provided the goals and objectives used in formulating the alternative plans and the recommended course of action. The detailed development of the goals focused on the following areas of concern: land use and management, erosion and sedimentation control, water quality management, fish and wildlife management, outdoor recreation development, drainage and flood damage reduction, water supply development, management of Maumee Bay, and legal, institutional, and legislative issues.

Throughout the Study, the alternative measures were refined and reevaluated in light of the goals and objectives established by the Citizen's Advisory Committee. Over 560 major alternative measures to solve various resource problems were identified during the course of the Study. The method of development and analysis of alternative plans and of the Recommended Level-B Plan were oriented toward the Principles and Standards for Water and Related Land Resources Planning. (Federal Register, Sept. 23, 1973).

Programs were developed for the categories of land resources management, erosion and sedimentation, water quality, wildlife, fishery resources, outdoor recreation, flooding, water supply, and Maumee Bay. Consideration was given to structural and nonstructural solutions regardless of whether the solutions would be undertaken by the private sector or by any of several units and levels of government.

All practicable management measures, both structural and nonstructural, were screened for effectiveness, acceptability, and technical feasibility for meeting problems, needs, and opportunities. Preservation, conservation, and development of water and related land resources were all considered. Various potential alternative components were not considered further because of lack of public interest, lack of economic justification, or due to technical considerations. In brief, more than 560 alternatives were suggested by the Citizens' Advisory Committee, the Planning Committee, and the Great Lakes Basin Commission. The Planning Board, in general, decided upon the alternatives to be investigated in detail.

Question 15:

The hierarchies and the various levels of responsibility for the decision-making process were discussed under Question 5 in Planning Stage 1.

The Planning Board was composed of planners who had utilized traditional methods in developing plans for water resources programs and projects. They were, in
general, not familiar with the surrogate worth trade-off (SWT) method or with the hierarchical techniques utilized in this method. They questioned the efficacy of developing a plan utilizing these methods which relied upon the Pareto optimum of the individual planner. They were accustomed to giving a single answer, in general, rather than a range of Pareto optimal solutions. Consequently, the consultants from CWRU had initially considerable difficulty in securing from individual members of the Planning Board their objectives and an articulation of their subjective trade-offs. Many times a person was unable to describe why he preferred a specific solution and what he was willing to give up to achieve it. Nevertheless, through iterative efforts, the objective trade-offs were generated via the SWT method, with various levels of decision-makers contributing to the surrogate worth trade-off functions. The trade-offs were obtained through an implicit process that was explicitly expressed by the SWT method.

A procedure for obtaining trade-offs can be found in Haimes and Hall (1974), Haimes (1980), and Chankong and Haimes (1982).

Question 16

Basically, the same set of constraints described in Question 4 extended its effect to this planning stage. Moreover, because of the complex, interstate nature of this Level-B planning effort, the basin was decomposed into planning subareas consisting of groups of counties. These planning subarea boundaries, although useful for efficient economic and demographic data collection, often did not coincide with the hydrologic boundaries. Therefore, some recommendations set forth by the Level-B Plan would have to be slightly modified before they could be integrated into other planning and resource agency efforts. For example, only those portions of the Plan in the hydrologic basin could be adopted as part of the Great Lakes Basin Plan.

Occasional gaps in the data base for the Level-B Study may present another methodological constraint on implementation. The study methodology focused directly on the utilization of existing data sources and not on the collection of new and original data. This factor, along with the fact that this study is the first in the basin that takes a multiobjective approach to planning and attempts to present a uniform level of detail for each planning element, provides the reason for occasional data gaps. These gaps may act as a constraint on the local, county, regional, or state official who seeks to implement a Level-B Plan recommended for a specific area. However, it must be recognized that where data gaps and needs for additional studies have been identified, specific recommendations thereon are embodied in the Level-B Plan.

One major legislative influence on the development of the water quality portion of the Study is the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500). This federal act sets up the framework for water quality planning throughout the nation.

The structure of the Study organization was one of the most difficult factors, and it posed a natural constraint that every study member faces constantly. It would be useful to describe the structural anatomy here to realize the Study situation.

The Maumee River Basin Planning Board consisted of one member from each of the following agencies: The Great Lakes Basin Commission (which also served as Study Manager); the U.S. Environmental Protection Agency; The U.S. Department of Agriculture, Soil Conservation Service; the U.S. Army Corps of
Engineers; the U.S. Department of the Interior, Bureau of Outdoor Recreation; the Ohio Environmental Protection Agency; the Indiana Department of Natural Resources; and the Michigan Department of Natural Resources. A Steering Committee, made up of higher-level representatives from the above agencies, was charged with resolving possible conflicts among the agencies at Planning Board level and providing guidelines for policy issues.

Question 17

The following models were used:

1) the MORE model (Multiple Objective Resources Evaluation)  
   An analytical linear programming model for agricultural analysis developed by the Economic Research Service, U.S. Department of Agricultural, for general usage.

2) the SWT method (Surrogate Worth Trade-off)  
   An analytical linear/nonlinear programming method for multi-objective optimization analysis developed by Yacov Y. Haimes and Warren A. Hall.

3) hydrological flood-plan models  
   A simulation model for hydrological analysis developed by the U.S. Army Corps of Engineers for general usage.

4) the Maumee Bay Study Model  
   A simulation model for the study of the Maumee Bay problems developed by the Great Lakes Environmental Research Laboratory--National Oceanic and Atmospheric Administration (GLERL-NOAA) (Dr. Arthus Pinsak) for this project.

5) the generalized reduced gradient model  
   An effective nonlinear optimization package—the generalized reduced gradient (GRG) method was extensively used in conjunction with the SWT method for the generation of Pareto-optimal solutions and their associated trade-offs.
The MORE (multiple-objective resource evaluation) model, developed by the Economic Research Service, U.S. Department of Agriculture, was used extensively for modeling the distributed source pollution control, and its outputs were used to determine model coefficients. The MORE model was modified and extended to include multipollutant (sediment and phosphorus in our case) system objectives as well as other related but noncommensurable objectives such as recreation and the preservation of wildlife habitats.

Question 18

The Maumee Bay simulation model was constantly updated. The floodplain simulation model was in a reasonably mature state, requiring little modification. All the analytical models (MORE, SWT, GRG) were well tested, calibrated, and verified for data consistency and optimality of results.

Question 19

Most of the final plan was basically developed by the technical experts working within the limits set by the decision-makers of the Great Lakes Basin Commission, and they utilized to a great extent the preferences and objectives of the Citizens' Advisory Committee with respect to the type of projects needed in specific areas within the basin. However, the GLBC did change some portions of the plan developed by the technical experts before giving their approval.

Question 20

The Maumee River Basin Study was a planning effort that was truly interdisciplinary; however, an optimum mix of technical experts was not always available, particularly in the environmental quality field.

The Study pointed out the importance of some of the prerequisites for the success of any interdisciplinary study, such as developing mutual trust among the participants and helping each participant to realize that within his own discipline he can contribute to the overall study effort. Additional known conditions for project success that were important included the mutual development of cooperative spirit among participants, so that the natural bias among the disciplines could be overcome and participants could come to tolerate opposing points of view, approaches, and beliefs. The time needed for these conditions to develop and mature and the fact that almost every participant joined the team with his own preconceived notion of what constitutes a level-B planning study may explain the time spent during the first phases in philosophical and sometimes trivial discussions. It is here that well-developed and acceptable guidelines for regional or river-basin planning would have the most impact on streamlining these costly, time-consuming debates. Such guidelines could in the future provide a general framework and platform for an acceptable starting point in the planning process.

5. Planning Stage 4: Development of Final Project Specifications

Question 21

Generally speaking, linear and nonlinear programming techniques were used to deal with the analytical models and simulation techniques were used in the simulation models (see Question 17). The most theoretically sophisticated (though quite straightforward) methodology used in analyzing the Maumee River Basin multiobjective problem was the surrogate worth trade-off (SWT) method.
The basin's planning objectives were mathematically formulated within the optimization framework. The submodels for land management and water quality representing one or more of the objectives were developed and were then integrated to form the overall multiobjective planning model. Most of these models integrated into the multiobjective optimization framework were developed at CWRU during the research period. The surrogate worth trade-off methods and its extensions are discussed in detail in the following articles and books:


Hierarchical-multiobjective modeling is a natural approach that is responsive to the large scale and complexity of such systems as the Maumee River Basin. This approach is essential for handling the planning of large-scale water resources and environmental systems, because it takes into consideration the multiple objectives and goals of the system as well as most of the system's interactions. Hierarchical multiobjective analyses provide a potent approach for analyzing large-scale systems in the context of the decision-making process.

A discussion of model optimality can be found under Question 26.

The CWRU research team would recommend the use of the SWT approach in any similar study because of the following special characteristics of the method:

1. The SWT method properly leaves to specialized analysis the quantitative-predictive (scientific) aspects of an evaluation but clearly gives the decision-maker the right and responsibility to evaluate the merits of improving any one objective at the expense of any other, given the associated quantitative levels of achievement of all objectives.

2. Using the SWT method, the decision-maker interacts with the systems analyst and the mathematical model at a general and very moderate level. The decision-maker's preferences for a noninferior solution are constructed through the trade-off functions in the objective function space, which is familiar and meaningful to most decision-makers. Only then are they transferred to the decision space.

3. Since the identification of optimal preferences which lead to a specification of the best-compromise solution (also called the preferred solution) is direct with the decision-maker, the SWT method is very well suited to the analysis and optimization of multiobjective functions having multiple decision-makers.

4. The SWT method provides for a quantitative analysis of noncommensurable objective
5. When the number of objective functions is three or more, this method has an appreciable computational advantage over other existing methods (Cohon and Marks 1975).

Question 22

Where sufficient data were available, monetary benefits and costs were computed. The costed elements of the plans include both facilities and programs of a governmental or group type, and those individual programs that are normally fully or partially financed from public funds. Capital costs were calculated for both installation and technical assistance expenses, and they include labor, materials, equipment, rights-of-way, water rights, engineering, and administration. Other capital cost categories include agricultural erosion-control implementation, technical studies, and acquisition and development of recreation sites.

The capital projects were converted to annual costs using a 50-year life at the then-current federal discount rate of \(6 \frac{3}{8}\) percent. Exceptions to this were municipal waste-water and storm-water treatment facilities, which were costed for a 20-year life.

Operations, maintenance, and replacement (OM&R) costs refer to the annual cost for upkeep and management of in-place capital items. Annual costs are also calculated for projects not requiring a first-time capital expense. They include average annual costs, such as those for administration of land resources, and tax loss resulting from outdoor recreation development. These costs have been averaged for the fifteen-year period. For example, the operation, maintenance, and replacement costs in the plan are the average monetary outlays during the fifteen years rather than for the development in place in the year 1990.

Benefits of the alternative plans were developed in accordance with Principles and Standards guidelines. Where sufficient data were available, these benefits were quantified. This included such items as dollars of annual flood damages prevented; dollar value of the hunting, fishing and recreation days provided by the plan; and increased income accruing to residents of the basin as a result of increased employment at the construction projects suggested by the plan.

Question 23

An impact analysis, called an environmental impact analysis, was made in a preliminary or generalized fashion. No risk analysis was undertaken, except that which might be assumed for flood control projects where protection from flooding for different frequencies was indicated. Risk analysis might have been desirable for a greater portion of the measures proposed in the plan had adequate information been available upon which to base such an analysis. An environmental impact statement was required by federal law and provided a basis for judgment of the efficacy of the several elements of the plan.

Question 24

The Planning Board members were the principal decision-makers involved in the selection of preferred plans. They utilized all information available to them, including input from the CWRU research team concerning the Pareto optimum of the multiobjective optimization problem and the Citizens' Advisory Committee with respect to their recommendations and the ultimate selection of the National Economic Development (NED) and Environmental Quality (EQ) portions of the plan. The Great Lakes Basin Commission entered into the selection of elements of the final plan by selecting the portions of the NED and EQ elements to be incorporated in the final recommended plan.
In the multiobjective optimization scheme (the SWT method), the trade-off value between the $i^{th}$ and $j^{th}$ objective functions, $\lambda_{ij}$, provided a broad base of information, all of which was needed in the planning and decision-making process. It has been shown that

$$\lambda_{ij} = -\frac{\partial f_j}{\partial f_i}$$

These trade-off values were generated simultaneously with the Pareto-optimum solutions. It is quite important to note that the trade-off values and the corresponding Pareto-optimum solutions can be readily utilized in the decision-making process even without generating the surrogate worth functions that the SWT method calls for. In other words, while the SWT method in itself is composed of several consecutive phases, it is not mandatory to activate all phases to use the method. This fact is of paramount importance for analysts and users who might not necessarily appreciate the way the SWT method calls for interaction between analysts and decision-makers, and/or the generation of the surrogate worth functions.

All students of economics (and most, if not all water resources planners belong in this category) are familiar with and use the concept of marginal benefit and cost in their analysis. The trade-off values essentially represent the marginal value concept with the exception that the numerator might not necessarily be given in monetary units. In other words, while the "classical" marginal benefit might be given in terms of dollars per ton of sediment, the trade-off value might be given in terms of bushels of crop per ton of sediment.

The experience with the Maumee River Basin Planning Board shows that while the generation of the trade-off values in terms of units of the $j^{th}$ objective per unit of the $i^{th}$ objective is possible and analytically elegant, these values are not useful to the planners unless they are given in terms of dollars per unit of the $i^{th}$ objective. That is to say, in applying the SWT method, it is preferable to have the primary objective function be the cost (or benefit) function, given in monetary units, while all other objectives in the $\varepsilon$-constraint formulation are in their own units. Two observations are in order at this time.

i) The preference of the Planning Board for monetary units is not unexpected since people do usually make decisions on trade-offs using the dollar as a basis. It is much easier for a Planning Board member to relate his attitude toward an alternative plan when the trade-off value is given in $$/ton-sediment rather than bushels of corn/ton-sediment or visitor-day/bushel of corn.

ii) The above reference in a trade-off presentation does not impose any hardship on the SWT method. It is always possible to select the monetary objective function in a multiobjective optimization problem as the primary objective in the $\varepsilon$-constraint formulation. If such does not exist, then one should select as the primary objective, that objective which can serve as a common denominator for a trading base. Furthermore, it is always possible to generate all possible trade-offs between any two objectives once the set $\lambda_{12}...\lambda_{ln}$ is generated. This can be done, as was mentioned, by using the formula

$$\lambda_{ij} = \lambda_{ik} \cdot \lambda_{kj}, i \neq j; i,j=1,2,...,n.$$  

The availability to the planners of the trade-off values at corresponding levels of achievement of various objectives can serve several very important purposes in the planning and decision-making process. Among these are:

i) The identification and recognition of the characteristics associated with each planning
subarea (PSA) -- hydrologic, geographic-morphologic, land and soil types, economic, socio-economic, and others. This type of information should assist the planner in maximizing the allocation of resources on a basinwide basis within the unavoidable constraints and thus enhance the likelihood of achieving the planning objectives and goals.

ii) The sensitivity in the changes of the trade-off values among the alternative plans are valuable information to the planners.

In summary, while the trade-off values are essential in the generation of the surrogate worth functions via interaction between analyst and decision-makers and the ultimate generation of a selected, preferred, and acceptable plan using the SWT method in its entirety, it is possible to utilize the trade-off values and to deduce many separate conclusions that can be very valuable to the planners and decision-makers.

In the applications of the surrogate worth-trade off method in the Maumee River Basin Study, the method's final phase, namely, the generation of the surrogate worth functions, was implemented. The intent of these functions is to essentially assist in representing the decision-makers' preferences in the selection of the final recommended plan.

In this study, there was a continuous and close interaction between the analysts and the decision-makers at various levels of the decision-making hierarchy. Each of these levels had its own influence and impact on the study outcome. Very often, the analysts were the decision-makers themselves. The hierarchy of decision-makers consisted of the Planning Board members and their close associates, who in turn centralized the data and provided the needed technical information to the Planning Board members. In addition, this hierarchy included the Study Manager, his staff, and his associates at the executive level of the Great Lakes Basin Commission, the Great Lakes Basin Commission itself, the Citizens' Advisory Committee, the Study Committee, the Steering Committee, the Water Resources Council, the public through various hearings, and other agencies who were not represented in the above groups of the decision-makers but who have influence in the region.

In summary, of all levels of the decision-making hierarchy in the Maumee Level-B Study, the Planning Board and the Study Manager had the most impact on the study outcome. Consequently, in generating the surrogate worth trade-off functions, namely, the preferences of the decision-makers over the various alternative Pareto optimal plans, only the Planning Board (the Study Manager is the chairman of the Board) was requested to state its preferences. This was done by soliciting the preferences of each Planning Board member. The resulting indifference bands of each Planning Board member did not always overlap, as would be expected. In comparing the final recommended plan and the displayed preferences of the Board members, however, it becomes evident that this plan coincides with the preferences of the majority of the Planning Board members.

It is very difficult at this time to accurately assess the impact that the generation of the preferences (via the surrogate worth functions) had on the plan which was recommended for final selection. It is much easier, however, to assert that the availability of the trade-off values among the various objectives and the corresponding Pareto-optimal solutions were extremely valuable in helping the decision-makers understand and analyze the various alternative plans and ultimately helped generate a recommended plan that is more responsive to the basin's needs. A major gap between the planning process and the implementation of
the resulting plans was discovered as a consequence of the generation and display of the trade-off values as they related to the various planning subareas.

**Question 25.**

A hierarchical multiobjective modeling and optimization structure was developed for handling comprehensive planning in the Maumee River Basin. Two major components of noncommensuration were identified in modeling the problem: one relates to economic objectives and the other to environmental quality as affected by point and nonpoint source pollutants, recreation, wildlife, etc.

A computer program was worked out which is capable of generating alternative policies and planning activities and their associated trade-offs using the surrogate worth trade-off method. The analysis was carried out with respect to each of the five planning subareas that are based on state and county boundaries in the basin. The level of objectives and appropriate trade-offs among the various objectives were determined for a range of feasible alternative plans: environmental quality (EQ), minimum EQ, economic development (ED), minimum ED, and a recommended plan. As inferred by name, minimum EQ places somewhat less emphasis on environmental quality in comparison with the environmental quality (EQ) plan, while minimum ED places less emphasis on economic development in comparison with the economic development (ED) plan.

The SWT method might be viewed at this stage of the planning process as a "simulation" method.

This distinct attribute of the SWT method is notable in light of the present proliferation of multiobjective methodologies developed for water resources planning.

**Question 26**

Recognition of the fact that the term "optimal solution" pertains to the model's optimal solution and not necessarily to the real system's optimal solution would help reduce some of the misgivings of the practitioners and at the same time help the modelers and analysts develop a more sober attitude toward the phrase. Furthermore, the model's optimal solution and the various scenarios and alternative plans that could be generated via the mathematical models should be invaluable tools in the decision-making process in general and in water resources planning in particular. For the Maumee River Basin Level-B Study, the "optimal solution" of the real system depended upon the value system of the decision-makers. The alternatives were not evaluated on a common basis, such as dollars to be compared directly against cost, but utilized output, such as acres prevented from flooding, visitor days, etc. Consequently, the SWT method provided as good an evaluation of the relative merits of the multiple objectives as was available. The decision-makers were at first reluctant to accept the results of the SWT method but, lacking a more definitive method of their own and being required by the SWT practitioners to state their preferences more succinctly, they derived a benefit from the SWT method in deciding which alternatives to recommend.

**Question 27**

The Planning Board made its recommendations to the Basin Commission and furnished the comments of the Citizens' Advisory Committee on the several recommended alternatives. The Basin Commission held a series of public meetings to obtain the views of the general public in addition to those of the Citizens' Advisory Committee who, by and large, attended the meetings in
their own areas to make the final recommendations for transmittal to their governors and the Water Resources Council.

Question 28

This question implies funding for the implementation of the final plan. The final plan was not implemented nor was it financed for implementation. However, as recently as 1982, the state of Ohio is continuing to evaluate recommendations for water resources projects in the basin in relation to the information presented in the plan to assist in the judgmental processes for approval of plans. Therefore, while no direct implementation of the plan is involved, it is being utilized as a standard from which to gauge other plans.

Question 29

No systematic post-planning evaluation of the overall plan has been completed to the knowledge of the former Basin Commission staff. Some post-planning evaluation has been undertaken in each of the states in considering work to be endorsed. The recommendations with regard to types of agricultural practices to be undertaken are being introduced to an increasing degree throughout the basin.

6. Planning Stage 5: Project Design

Question 30

Question 30 does not apply to the state of planning or the level of planning for the Maumee River Basin Study.

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References


THE PLANNING PROCESS IN THE METROPOLITAN
ADELAIDE WATER RESOURCES STUDY OF JUNE 1978

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Introduction

Adelaide is the capital city and the largest city of the state of South Australia, which is the driest state of the country which occupies the world's driest continent (see Figure). Metropolitan Adelaide had in 1982 a population of almost one million. It draws its water from storages on nearby streams and, increasingly, from the comparatively large and reliable flow of the River Murray. However, water from the River Murray is more saline and more turbid than from the nearby streams.

1. Planning Stage 1:
Project Initiation and Preliminary Planning

Question 1

The project was initiated on the basis of a long-term programme. The Metropolitan Adelaide Water Resources Study, begun in 1976 and completed in 1978, was an investigation into how to provide a water supply for metropolitan Adelaide over the next 30 years.

Question 2

The only agency directly involved in the project was the Engineering and Water Supply Department of South Australia. It was responsible at the time of the study to the Minister of Works and is now responsible to the Minister of Water Resources (of the Government of South Australia) for rural and urban water supplies, amongst other things, throughout the state. Its Director-General and Engineer-in-Chief is currently the Chairman of the South Australian Water Resources Council, on which a number of bodies concerned with water are represented, and which is concerned with an integrated approach to water resources management for the state. The Engineering and Water Supply Department also interacts with the River Murray Commission, a body on which are represented the governments of the states of South Australia, Victoria and New South Wales and the Commonwealth Government (the federal government of Australia). The River Murray Commission administers the River Murray Waters Agreement (an inter-state compact) which allocates among the states water from the River Murray on which Adelaide depends heavily.

The skilled personnel involved in the planning process were engineers and an engineer-economist of the Engineering and Water Supply Department. Public participation was not explicitly involved in the formulation of project objectives, but reports on the study were made available for public scrutiny and comment. There has been subsequent public involvement in demand management and in the development of a corporate plan for the Department. (See also the answer to Question 13).

Question 3

The investigation, which led to recommendations for a programme of works construction over a period of
time and for particular operating policies, was initiated by a recognition that the quality of the water supply had to be improved, that public funds were becoming scarce and were likely to remain scarce for many years, that continuing supply to the city of Adelaide was becoming increasingly dependent of the River Murray, and that the rate of population growth of the city had declined since the completion of the previous major investigation in 1973.

Question 4

The only constraints were self-imposed. They were that the study should be completed in two years, and that it should deal with the problem of providing Adelaide with water over the next 30 years.

Question 5

The methods employed were developed by the officers of the Department, mostly younger engineers. There were no disagreements.

2. Planning Stage 2: Data Collection and Processing

Question 6

Data used comprised:

Streamflow and rainfall records for the Adelaide Region (the area of local supply);

Streamflow records for the River Murray;

Consumption records for water in Adelaide for different consumer classes and sub-areas (over the area of consumption);

Evaporation and rainfall for Adelaide at different locations representing different sub-areas;

Population records in different sub-areas (and population

Question 7

Existing data were supplemented with 50 separate sets of synthetically generated data. Each set consisted of generated streamflows at ten locations and generated demands at eight locations. The demands were derived from generated rainfall and rainfall/consumption correlations. Net evaporation losses were also generated. Forecasts of demand over the planning period were made.

All measurements are being continued during the construction period and will be continued indefinitely into the future.

Question 8

Operations research techniques were not used to decide on the method of data collection and length of data.

Question 9

A programme was not set up to assess the availability of the data base used.

Question 10

No special methods were used to analyse the data

3. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11

The entire study (Planning Stages 1 to 4 inclusive) took approximately ten man-years of professional effort with about the same amount of sub-professional support. The study was internally funded as part of the ordinary expenditure of the Department. Use was made of the South Australian Government's Automatic Data Processing Centre which had a Control Data Cyber 73.
Question 12

The only support from outside the Department was assistance in making population forecasts by other state government departments.

Question 13

The public did not participate at all in the planning and decision-making process, because, so far, the issues have been simple, the alternatives similar in their social and environmental impacts, and non-one's special interests have yet been seriously threatened. The Engineering and Water Supply Department is not averse to public participation; it initiated a public participation programme in 1976 in connection with River Murray salinity control (Allen and Killick, 1979).

Question 14

Thirteen distinct alternatives were investigated, all in sufficient detail to enable "indicative" costs to be estimated. The alternatives considered were decided on by the members of the study team as an integral part of the study.

Question 15

The standard project planning procedure of the Department was followed whereby the project is discussed continually as it progresses with information flowing upwards through the hierarchy of responsibility to senior management. In this case the views flowing back down the hierarchy were confirmatory. In addition, every month brief summaries of progress were sent to the South Australian Water Resources Council and to the Minister. These resulted in very little disagreement.

Question 16

No constraints were imposed.

Question 17

Multi-dimenional simulation with time discretized into months and with synthetically generated inputs was used in conjunction with two-level hierarchical decomposition and deterministic dynamic programming for sub-system optimization. The hierarchical decomposition was adapted from the approach proposed by Haines and Macko (1973). The dynamic programming model was developed to suit the circumstances of the problem. The objective function was to minimize pumping costs over the 30-year planning period subject to system component capacity constraints and minimum target storage levels representing levels of security or risk.

Question 18

To the extent that the models dealt with volumes of water and costs of pumping, calibration and verification were not required. Testing and modification were concerned with computational efficacy.

Question 19

The experts recommended the first stages of a final plan and the deferment of some decisions until later to the Minister. The Minister and the South Australian Government accepted the recommendations. The public was informed, and there was no adverse reaction.

Question 20

The planning team was composed mostly of engineers. The majority were civil engineers, but there was one electrical engineer with a specialisation in operational research. One of the civil engineers was also an economist. Other disciplines were involved in population forecasting. To this extent the study was interdisciplinary, with the mix seeming to be appropriate.
4. Planning Stage 4: Development of Final Project Specifications

Question 21

In this study, Planning Stages 3 and 4 were not distinct, and the answer to Question 17 above partly answers Question 21.

The following paper and books were helpful:


There were some small simplifications of the problem to give a simpler model. For instance, a couple of reservoirs were lumped and a pumping station was omitted. Also the division into subsystems involved some simplification. The model was not "optimized". The alternatives available did not seem to be many; the choice came down to brute force simulation or dynamic programming with decomposition, and the latter was chosen on grounds of economy in computing. The approach would be used again. The development of the model took many months.

Question 22

A cost benefit analysis as such was not undertaken; rather, a cost risk analysis was made. It seemed more appropriate to the circum-

Question 23

A risk analysis (See Question 22 above) was made at the suggestion of the Department to the decision-maker, i.e., the Minister, who approved. What was learned from it were the conclusions made in the report on the study and the recommendations following from them. That is to say that the cost risk analysis lay at the heart of the method used to draw conclusions.

Other impacts were not considered in any detail.

Question 24

It so happened that it was possible to make immediate decisions without having to consider the trade-off between cost and risk or any other trade-off. The immediate decision, involving the configuration within the supply network of water treatment plants and their capacities to be constructed within the next few years, was made on a simple cost minimizing basis.

However, the study highlighted the major trade-off issues for future decision-making.

A multi-objective optimization methodology was not used; environmental issues did not arise because alternatives had approximately the same impacts among those involved in immediate decisions, and compromise among objectives has been deferred for later decisions. The involvement of decision-makers (at the various levels) in the selection process has been given in the answer to Question 15.

The conclusions and recommendations that can be shared are that in an amiable social environment decision-making is easy, and that sometimes difficult decision-making problems can be deferred.

Question 25

As indicated in the answer to Question 24 above, no trade-off analysis was made, because it was possible to defer it.
The decision-maker did accept the "optimal" solution generated by the model and did accept the approach without supplementation by "conventional information", but the procedures used already by operators with a "feel" for the system were consistent with the results of this study.

The final plan was sent in the form of a recommendation to the Minister, who referred it to the South Australian Water Resources Council for advice. This Council is made up of the heads of the Department and other government agencies and representatives of major public interest groups. It, in its advice to the Minister, agreed with the recommendation. This was then agreed to by the Government of South Australia.

For funding the final plan, long-established process was used of arranging for State Government loan funds with supplementation from Commonwealth (federal) grants.

A continuing evaluation is being carried out. The planning undertaken in the study being described has not terminated, nor has continuing evaluation ceased. For instance, work is now proceeding on the development of detailed operating procedures with updated data and modified models.

Acknowledgement

Thanks are due to Mr. K.J. Shepherd of the Engineering and Water Supply Department, South Australia, for many clarifications. Any obscurities and mistakes are the responsibility of the author.

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POST EVALUATION OF THE PLANNING PROCESS
IN THE VISTULA RIVER BASIN, POLAND

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1. Preface

The following positions were held by the co-authors at the time the Vistula River Project ("Planning Comprehensive Development of the Vistula River System") was conducted (1968-1971):

Zdzislaw Kaczmarek:
Professor and Director,
Institute of Environmental Engineering, Warsaw Technical University; in charge of the inter-institutional team of Polish scientists and practitioners developing project methodology.

Janusz Kindler:
Acting Director, Bureau of the Plan of Operation "Vistula"; Project Co-Manager responsible for project mobilization and execution jointly with the Project Manager appointed by the UNDP; later Chief Project Engineer and member of the team charged with development of project methodology.

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1

The first long-term national water resources development plan was drafted by the Polish Academy of Sciences in the years 1953-1956 (time horizon of 1975). The plan was then twice revised in the early 60s by the National Water Authority, and the time horizon extended to 1985. By 1968, it became clear that the water situation, particularly in the Vistula River Basin which covers about 54% of the country's area, required special attention. Preliminary long-term projections developed by the Planning Commission and the Polish Academy of Sciences indicated that the state of water availability in the basin was not compatible with future demands. In 1968, comprehensive studies were initiated with the assistance of the United Nations Development program and the United Nations itself, under the name of the "Vistula River Project" ("Planning Comprehensive Development of the Vistula River System").

The goal of the project was to formulate a water resources development (investment) program capable of meeting demands projected to the years 1985 and 2000. It was assumed that the project would make use of all possible improvements in the methodology of designing and operating large-scale and complex water resource systems (application of mathematical techniques, computer simulation, and the like).
Continuous revision and verification of plans is unavoidable in a rapidly expanding economy; the value of an operational tool for quick evaluation of the consequences to water management of some new development concepts and alternatives cannot be exaggerated.

**Question 2**

On the Polish side, "Hydroprojekt", a firm of consulting engineers operating within the framework of the National Water Authority, was charged with the preparation of the project and its coordination with about 40 research institutes representing 14 ministries concerned and several universities. The development of project methodology was assigned to a specially created team of about 20 specialists representing university institutes and various organizations of the National Water Authority. From the UNDP side, an international panel of experts assisted the Polish team throughout the entire duration of the study. Assistance in the development of project methodology was entrusted by the UNDP to Water Resources Engineers, Inc., Walnut Creek, California, U.S.A.

There was no public involvement in the project preparation. Project objectives were formulated by the National Water Authority.

**Question 3**

See 1 above

**Question 4**

The only constraints imposed on the study were those resulting from the Water Law, Water Quality Act, and other governmental decrees and regulations in force in Poland at the time of project preparation.

**Question 5**

The methodological work was first organized around a basic scheme proposed by the Institute of Environmental Engineering of Warsaw Technical University. The so-called Three-Step Method is composed of three computer programs which are applied sequentially in order to: (1) determine a set of target releases for individual reservoirs in the system, (2) develop operating rules for the reservoirs given the inflow hydrology and the target outflows, and (3) determine the optimal allocation of available water to all water uses considered in the model, given the operating rules from (2). Steps (1) and (3) were based on the Out-of-Kilter Algorithm, which is a special-purpose linear programming method derived from network flow theory. Step (2) was based on the method developed by Kornatowski (1969), employing stochastic dynamic programming. Details of the Three-Step Method are described by Kaczmarek et al. (1971). The programs were made operational on the Polish-made Odra 1204 and 1304 computers; however, they could not be combined into a single program because of the limited capacity of the machines available at that time. Under the circumstances, implementation of the method was rather difficult and attention was focused on the development of the so-called Single-Step Method (referred to as the WRM Model). That method utilizes the Out-of-Kilter Algorithm to solve water resource allocation problems in a complex multi-reservoir system (see King et al., 1971).

3. Planning Stage 2: Data Collection and Processing

**Question 6**

A starting point for methodological studies was a proposal made by the Institute of Environmental Engineering, Warsaw Technical University, for a spatial and problem-oriented decomposition of the system. Such a decomposition was justified by the exceptional size of the Vistula River Basin, the large number of users, the complicated system structure, and the limited computer facilities available at that time. It was decided, therefore, to decompose the
basin spatially into 13 subsystems. Each of these represents an area whose economic structure is as uniform as possible, which is of homogeneous hydrological nature, and which creates similar hydraulic engineering problems.

With regard to problem-oriented decomposition, the proposal—in conformity with the special character of water management in Poland—was directed mainly toward the problem of water supply for the population, agriculture, and industry; toward water pollution control; and toward independent investigation of the most rational solutions for flood control.

The list of water control objectives identified in the "Vistula River Project" included:

1) Water supply to the population, agriculture and industry;

2) Maintenance of the minimum acceptable flows (established via a detailed study of the environmental effects of various minimum flows);

3) Water pollution control;

4) Flood control;

5) Development of recreational facilities;

6) Development of hydropower production and inland navigation, taking into consideration the effectiveness of alternative power production and transport modes.

The target values of all water control objectives have been established by the specialized agencies (14 ministries in collaboration) for two levels of future development, 1985 and 2000. The common base for all projections has been the national long-term development plan. Final compilation, critical evaluation, and preparation of these data has been assigned to the National Water Authority and its agencies, especially the "Hydroyekt" previously mentioned.

For water supply studies, 15 years of historical mean monthly flows were used. Different hydrologic data were used for the water quality studies, flood control, and hydropower production.

Question 7
Only existing data were used after their intensive processing as to match requirements of methods employed for project preparation.

Question 8a. No.

Question 8b. No.

Question 9. No

Question 10. Regression analysis was used for estimation of water requirements. Network flow methods were used for transferring streamflow data from gauging stations to supply/use balancing nodes.

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11. See Planning Stage 1.

Question 12. Project execution was authorized by the Governmental Decree specifying all institutions involved and obliging them to mobilize appropriate manpower and financial resources.
Question 13.
No participation

Question 14.
Altogether, 148 investment and water use alternatives were analyzed: 46 for the time horizon of 1985 and 102 for the year 2000. Alternatives were specified by "Hydoprojekt" with the assistance of the ministries concerned.

Question 15.
Conflicts in water use were analyzed by assigning weights to different uses reflecting their mutual priorities. The system of priority weights was developed by the project team.

Question 16.
See Question 4 above.

Question 17.
a) The WRM Model; simulation/optimization package for analysis of water resources allocation, including reservoirs operation.

b) The POWDYN Model; dynamic programming for determination of the optimal reservoir operating policies for hydropower production.

c) The POWREC Model; simulation for computation of the hydroenergy outputs.

d) The modified SSARR Model; flood propagation analysis.

All models were developed during the project.

Question 18.
All models were tested through application against detailed data in the most complex of the river basin subsystems.

Question 19.
"Hydoprojekt" presented a few "best" alternatives to the Ministry of Agriculture (which replaced the former National Water Authority) which next presented a selected alternative to the government for final approval. In 1976, the government approved the plan and allocated the necessary funds for project implementation (detailed allocation for the nearest 5-year plan and directional allocation until the year 2000). In 1978, a new organization was set up for project implementation. Since 1980, project implementation has been kept at a significantly reduced level because of the overall economic difficulties of the country.

Question 20.
Yes, it was.

5. Planning Stages 4 and 5

These stages do not apply to the level of planning in the Vistula River Basin.

References


1. Introduction

The Susaa-Project is a 5-year hydrological research project initiated in 1977 as the Danish contribution to the IHP and completed in the beginning of 1982.

The Susaa catchment covers approximately 750 square kilometers and is situated in the central and southern part of Zealand 50-70 km south-west of Copenhagen, see Fig. 1.

The Susaa basin is underlain by a regional artesian aquifer consisting of limestone deposits covered by semipermeable glacial deposits of clayey moraine.

The water supply of municipalities and industries is generally based on distributed low-intensive groundwater abstraction schemes. However, a centralized high-intensive groundwater abstraction for the benefit of Copenhagen is located just outside the north-eastern part of the catchment. In addition Copenhagen utilizes the two lakes Haraldsted so and Gyrstinge so as supplementary surface water reservoirs.

The present groundwater abstraction for irrigation purposes is rather limited, but the interest among farmers has increased. Especially the 1975-1977 droughts gave rise to a boom in licence applications. Irrigation based directly on surface water resources is very limited and will not be permitted in the future due to low flow conditions during the irrigation season.

Low flow augmentation by means of groundwater has not yet been applied in Denmark. The interest in investigating this possibility of eliminating low flow calamities is, however, strongly increasing.

There are great recreational and conservation interests attached to the area. Especially the lake Tystrup and its surrounding area is a site of great concern. The streams within the basin are in general also subject to public awareness in terms of both their quality and quantity primarily for the purpose of ecology and recreation including fishing and canoeing.

The Susaa as well as its tributaries act as recipients for municipal sewage. The waste-water treatment plants operate at different levels, but except for some minor plants with only mechanical treatment the plants provide at least biological treatment.

The northern part of the Susaa catchment is shown in more detail in Fig. 2. The management part of the entire Susaa project is in particular the subject for the answering of this questionnaire.
Fig. 1  Zealand and the location of the Susaa Catchment
Fig. 2  The northern part of the Susaa Catchment
2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1:

In 1970 the total consumption of water in Zealand was estimated to be 35% of the maximum amount which was considered possible to withdraw without paying any attention to the environmental consequences. The demand for the year 2000 was forecasted to be 50%. Thus, taking also the impact on the environment into account, serious problems could be foreseen.

The largest expansion of the water withdrawal was planned to take place within the Susaa basin. The cities of Naestved and especially Copenhagen were carrying out a series of preinvestigations, but the final decision for the implementation of the expansion schemes was not taken, one of the reasons being the public concern of possible environmental damages. As a consequence of the increasing environmental awareness, the Minister for Environmental Affairs asked the Danish National Agency for Environmental Protection and the three regional administrations of Zealand to plan an investigation of the ecological consequences of an increasing groundwater abstraction in Zealand. For the above mentioned reasons it was decided to perform the investigations in the Susaa basin. At that time the Danish Committee for Hydrology was formed as the committee responsible for the Danish participation in the IHP. Because the objectives of the IHP corresponded very well with the objectives of the current investigations, the committee selected the Susaa basin as a research area.

The main objective of the project was to study the hydrological and to some extent the ecological and economic consequences of increased water resources development; and to develop appropriate tools for water resources management.

Seven research institutions participated in the Susaa project. The study was financed by the Danish National Agency of Environmental Protection, the Danish Agricultural and Veterinary Research Council, the Danish Natural Science Research Council, the Danish Technical Research Council and the Danish National Agency of Technology.

Question 2:

The Susaa research programme was outlined by a working group comprising representatives of Danish institutions dealing with hydrology. The sub-project concerning management of the water resources was planned in detail by the three institutions taking part herein: 1) Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, 2) the Water Quality Institute, and 3) the Danish Land Development Service. The Danish Committee for Hydrology was responsible for the entire Susaa-project. The public was not involved directly.

Question 3:

One of the main reasons for the successful application of financial support to the project was the appearance of a new water resources development act which requested comprehensive water resources planning on the regional level taking into consideration:

* the quantity of the water resources.

* the public, industrial and agricultural needs, for a sufficient water supply, both quantitatively and qualitatively.

* environmental protection (protection/conservation of the the environmental and recreational values).

* other public considerations, among those the use of raw materials.
Thus the planning should recognize and solve the conflicts between the different interests representing water supply, waste water disposal, irrigation, recreation and conservation of wet areas. It was commonly agreed that this would require more insight into the hydrological processes and development of more appropriate planning tools.

Question 4:

The constraints were primarily of a financial character. After negotiations giving rise to some reductions in the proposal for the research programme, the project was accepted by the financial institutions mentioned in the answer to question 1.

Question 5:

Because all the research institutions participating in the project as well as the financing institutions were strongly involved in the preliminary planning phase, the final research programme became fully accepted.

The entire Susaa project comprised:

* Field studies of hydrologic processes.

* Mathematical modelling of hydrologic processes and systems.

* Management of water resources.

The general purpose of the management part of the Susaa project was to develop mathematical models suitable for water resources planning purposes. The various possibilities for model formulation was evaluated in the preliminary planning phase, and a combined model which was able to simulate the joint effects of water abstraction and sewage disposal in the Susaa catchment was found most convenient for detailed studies of the consequences of various planning schemes.

3. Planning Stage 2: Data Collection and Processing

Questions 6 and 7:

Hydrologic and water quality data were used to calibrate the submodels of the total simulation model. The following is not a complete description, but only a listing, with the purpose to give an idea of the types and the proportions of the applied data, which partly comprised already existing data and partly data collected during the project phase.

For the hydrological submodels series of precipitation, streamflow, potential evapotranspiration, and temperature data taken on a daily basis from several stations in the basin were used. Furthermore, groundwater level observations, long term as well as short term in connection with pumping tests, were applied. Registrations of groundwater abstractions and discharges of waste water treatment plants were also taken into account.

Water quality streamflow data were collected during intensive 2-day measurement periods, where primarily the discharge and the variation in the oxygen concentration were observed. Further data for calibration of the streamflow quality model were used for example the load of organic matter originating from diffuse sources, plus the geometrics of the considered streams. The water quality of lake models was calibrated on the basis of measurements of data showing the primary production, concentration of total nitrogen, total phosphorous, oxygen, chlorophyll, etc.

One of the intentions of the project was to analyse examples of future dispositions for the water resource on a basis as realistic as possible. Therefore a large effort was made to collect precise data with regard to existing dispositions, forecasts of the future demands and the disposition plans already worked out. These
models comprise the development of waterworks for local supply in the Susaa catchment and the so-called paragraph 21 plans for the future waste water treatment within the basin (referring to paragraph 21 in the Danish environmental protection act).

Finally, economic data concerning construction costs and operation costs of waterworks and waste water treatment plants were collected. Hereby the consequences of various water resources schemes can be compared also in economic terms.

Question 8:

No OR technique was used in connection with data collection and processing.

Question 9:

A databank was established for all data collected as part of the hydrological investigations in the Susaa area. This promoted the exchange of data between the subprojects and ensured the storage of data in an operational form.

Question 10:

See the answers to Questions 6 and 7.

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11:

In the management part of the Sua-project it was initially agreed that the main activity should be to develop an overall simulation model which was able to calculate the integrated effects of water abstraction and waste water disposal in the catchment, by combining a series of quantity and quality sub-models. In the preliminary phase of the project period the possibilities of applying optimization models were examined in detail, but the conclusion was that developing an overall optimization model was outside the scope of the project. The preliminary project phase covered approximately 6 months in which the optimization analysis and final project specification was worked out by a study group comprising representatives from the three participating institutions.

Question 12:

During the project period some of the participating institutions supported the project by allocating more research manpower than granted by the financing institutions and by providing rooms and secretarial assistance free of charge for the project.

Question 13:

The public did not participate in the research planning process.

Question 14:

The objective of the project was to develop a tool suitable for investigating alternative dispositions for the use of the water resource, taking into account conflicting interests such as: abstraction for local and external public water supply, irrigation of farmland, recreational use of streams and lakes, use of the streams as recipients for treated waste water.

Question 15:

In the preliminary project phase, it was realized that the choice of a simulation model type implied some shortcomings. Trade-offs could not be explicitly determined and the model was not able to find the "optimal" scheme for a certain choice of local and external demands, irrigation permissions, minimum discharges at various stations and selected water quality standards etc. However, the possibilities for obtaining detailed information of the hydrological, the water quality, and the economic consequences of selected schemes were found more important.
In the analysis of the possibilities of developing an overall optimization model it was realized that only a model with a hierarchical structure could be used. This structure was outlined, but not worked out in full detail.

**Question 16:**

No further constraints were imposed in the planning phase.

**Question 17:**

The developed simulation model consists of a series of hydrological and water quality submodels which aim to provide a unified basis for water resources management. The sub-models can be divided into a hydrological and a water quality model complex, supplemented with programs that calculate the economic consequences of the chosen regional water resources scheme.

The main hydrological submodel is an integrated surface/subsurface catchment model, which allows for simulation of soil moisture in the root zone, evaporation, flow in tile-drains, streamflow and seepage to and flow through aquifers. This model is extended with models for irrigation, for management of surface reservoirs and for low-flow augmentation. The model thus takes into consideration the conjunctive use of surface and groundwater resources with the intention of providing water for supply, while maintaining adequate streamflows.

The water quality model complex utilizes inputs concerning the waste water treatment scheme (location, capacity and removal efficiency of the treatment facilities and by-passing configurations) together with information about critical streamflows and possible low-flow augmentations simulated by the hydrologic model complex. This allows for simulation of the water quality in streams. Furthermore, the water quality complex calculates the load of nutrients on two of the lakes in the basin, by means of which the water quality herein can be determined.

For given water resources dispositions the total model operates as standard during a time period of 31 years, utilizing meteorological data from the period 1950-1980 on a daily basis as input. This allows the consequences to be evaluated on the basis of the climatic variations to be expected also in the future. Thereby a statistical assessment of the consequences, as well as a presentation of the consequences as functions of time (for example during a drought period) can be chosen. The coupling of the model complexes is shown in Fig. 3.

As standard the model simulates the hydraulic head of the primary groundwater in 112 locations, corresponding to the polygons shown in Fig. 4, the streamflow in 45 stations and the water level variations in the lakes on a daily basis.

The water quality in the lakes is calculated as the yearly primary production, while the quality in the streams is given as the variation of the oxygen concentration during a critical streamflow situation in the above mentioned 45 stations.

Add to this a series of possibilities for singling out special information, for example regarding irrigation, variation of the irrigation demand, increase of the evapotranspiration and the percolation, etc.

**Question 18:**

The different sub-models were tested, calibrated and verified in connection with various sub-projects within the entire Susaa project. To some extent they were modified when introduced into the total simulation model.

**Question 19:**

The selection of a final plan for water resources development in the area was outside the scope of the research programme.
Fig. 3 Coupling of the hydrological and the water quality model complex
Fig. 4 The Susaa catchment and the model area
**Question 20:**

The project was interdisciplinary only in the sense that both the quantity and the quality effects of potential water resources development schemes were handled simultaneously by the model, contrary to the traditional approach with more or less uncoordinated planning of water abstraction and sewage disposal, etc.

5. Planning Stage 4: Development of Final Project Specifications

**Question 21:**

OR methods were not used in the project. However, it is possible without any difficulties to extend the model by a sub-optimization of the waste water treatment facilities. With given quality standards for the stream and fixed capacities of the plants the treatment levels can be allocated in order to obtain minimum annual construction and operation costs.

**Question 22:**

No cost benefit analysis was made as part of the project.

**Question 23:**

No specific risk analysis was performed, but impact analysis was performed to a large extent as a substantial part of the project.

The practical use of the simulation model is shown in Fig. 5. The dispositions of the water resource to be analysed are specified by the user as input to the model. Depending on the needs for detailed information of the consequences, the user specifies to what extent the simulated results should appear as output from the model running.

A series of possible planning dispositions were analysed in order to exemplify the applicability of the model for planning purpose. It was the hope that this illustrative use of the model would encourage the water authorities concerned with the Susaa catchment to implement the model in the future planning process, as well as other water authorities, to develop similar models.

The reported examples of model simulation (see 1) comprise:

- Increase of surface water withdrawal for external use.
- Conjunctive abstraction of groundwater and surface water for export purposes.
- Groundwater abstraction for irrigation.
- Low flow augmentation.
- Alternative waste water treatment schemes.

Essential for selection of model simulation examples was the fact that the city of Copenhagen previously had shown great interest in the groundwater resources of the basin, thereby competing with local demand for water supply, recreation and irrigation.

**Questions 24 and 25:**

The consequences of specific plans for use of the water resources can be assessed in detail by the simulation model. A specific trade-off analysis was not included in the project. However, it is by means of the model possible to study the environmental and economic consequences of various alternatives for water resources development in the Susaa catchment, and to determine appropriate configurations of waterworks and sewage treatment plants.

**Question 26:**

No decision-makers were involved in the research project.
Fig. 5 Use of the simulation model
Questions 27 and 28:

No final plan was approved as part of the project.

Question 29:

The project group made on request of the Danish Committee of Hydrology a proposal for a generalization of system analysis models for water resources planning purposes. The Susaa project formed an essential basis for the proposal, which has not yet been granted.

After completion of the Susaa project the water resources management group was asked to perform a comprehensive documentation and updating of the model in order to make it possible for the regional water authorities to run the model. Unfortunately this project was confined to the hydrological model complex, so now the more operational version of the model does not include water quality and economic aspects. This project was financed by the Danish National Agency of Environment Protection together with the three regional water authorities of Zealand.

6. Planning Stage 5 - Project Design

Question 30:

No design was performed as part of the project.

Reference

MANAGEMENT OF ISRAEL'S WATER RESOURCES

By

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1. Introduction

In this case study we consider the use of the systems approach for planning and management of Israel's water resources. It is somewhat different from other case studies in this volume, because it spans many years of activity, covering a continuous process of plannings, in a water resources project which covers an entire country, albeit one whose size may not be much larger than some of the regions covered by other case studies.

A very substantial amount of water resources systems analysis work has been carried out in Israel since the early 1960's, spanning the entire spectrum from long range planning for the entire country down to real-time operation of local systems. A review to 1980 was published by Shamir (1980). Herein we shall answer the questionnaire with specific reference to the "Project Planning" part of our work. Still, this refers not to one particular study but to planning work for the national system and its regional components, work which has been done in many inter-related studies over the years.

Israel's water resources are managed by the Water Commissioner. The Hydrologic Service is responsible for data collection and analysis, and advises the Water Commissioner. Tahal-Water Planning for Israel, Ltd. is the national planner. Mekorot Water Co. Ltd. is the national water supplier. Development, adaptation and use of systems analysis methodologies and models have been carried out by these bodies, in close cooperation with universities.

The systems analysis work has been structured as a hierarchy (for details see Shamir, 1980): at the top are models of long range planning for the entire country, and as one progresses down the hierarchy of models the temporal and spatial detail increases. Some references are cited at the end of this case study. This is but a sample, since an extensive list would be too long. Also, much of the work, even when new methodologies were being developed and tested, is described only in project reports, most of them in Hebrew.

Next we give a brief description of Israel's water resources and needs, and then proceed to answer the questionnaire.

Israel (Figure 1) is located in a semi-arid area, where mean annual precipitation averages 25-50 mm in the south, 500-600 mm in the central regions, and reaches 700-1100 mm in the north. About 80% of the total precipitation occurs in the northern half of the country, almost entirely between October and March. The country's area is about 20,000
FIG. 1: THE ISRAELI WATER SYSTEM
square kilometers, and the population is just over 4 million.

The proven natural water resources of Israel amount to approximately $1.85 \times 10^9$ m$^3$/year: about 60% is from groundwater, 30% is from Lake Kinneret (the Sea of Galilee), and the remainder is from other surface sources. Two thirds of the groundwater comes from two main aquifers: the coastal aquifers (a 5-30 km strip along the Mediterranean coast), and the deeper limestone aquifer to its east. These main sources are shown on Figure 1, together with the National Water Carrier. Completed in 1964, the National Carrier is the backbone of Israel's water supply system. It takes about $4 \times 10^8$ m$^3$/year from Lake Kinneret, and through connection to about 25 regional systems supplies and receives water along its route.

Most of the water potential is already developed, and in certain cases--notably the coastal aquifer--is over-exploited. The total amount available for supply depends on the policy for extraction from the sources: should it be balanced, i.e. not exceed the natural potential, or will over-draft be allowed for some period of time. If over-draft is allowed, this must eventually lead to a reduction of supplies, unless water can be produced economically from the remaining sources and/or by desalination. Use of reclaimed sewage for irrigation of certain crops is increasing, and is expected to reach $250-300 \times 10^6$ m$^3$/year.

Demand presently totals $1.85 \times 10^9$ m$^3$/year: 69% in agriculture, 22% urban and 9% industrial. 75\% m$^3$/year are allowed to flow from the coastal aquifer to the sea to provide some flushing of contaminants and contain the sea water intrusion. This brings total present use to $1.925 \times 10^9$ m$^3$/year, more than the average annual potential of the presently developed sources.

Until the late 1960's the main objective of Israel's water sector was development of the sources and of the conveyance and distribution systems, to bring water to all consumers. The water systems developed over the first two decades of the State's existence from a scattered collection of outdated local systems, each based on its own local sources, to an integrated national system. Once the main systems were in place, and demands reached and then exceeded the resource potential, the water sector has to deal with scarcity of water and competition among the consumers. The main issues and problems now are:

1. Completing the development of the remaining sources, which are problematic, remote, expensive, of low quality. These include some surface and ground water, reclaimed sewage and possibly desalination.

2. The pressure to increase supplies, on the one hand, and the responsibility to preserve the quantity and quality of water in the sources, on the other, must be resolved somehow in a balanced policy.

3. Operation of the National Water Carrier and the regional systems, which connect the main reservoirs and convey water over considerable distances, with the attendant problems of reliability and high energy costs.

4. A noticeable deterioration of water quality in some of the sources, primarily in the coastal aquifer.

5. Limited budgets, which severely constrain investments in new projects and maintenance of existing ones.

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1:

Long range planning is an integral component of the systems analysis work itself. The models at this level consider explicitly on the supply side the stochastic
nature of the available water resources, and on the demand side.

The expected increases in domestic demands and the productive uses of water in agriculture and industry. The results of the analysis at this level provide the framework for all of the more detailed regional and project level plans.

The answer to Question 1 is therefore that when a particular project is planned there is a long-term programme into which it must fit. At the same time, this long-term programme is not completely fixed, and actually evolves and changes as regional plans are studied.

**Question 2:**

For the last 20 years there have always been several teams of systems analysts working on various components of the studies. The total number of skilled personnel has ranged between about 10 and 30, in 4-5 groups at universities and operational agencies. The people's expertise are: water resources engineering, mathematics, statistics, computer sciences. Most hold Masters and Doctorate degrees.

The 'public' is always represented in Israel in the decision-making process, by virtue of the fact that representatives of several constituencies - notably the farmers - serve on some of the governing bodies.

**Question 3**

At the highest levels of the systems analysis hierarchy the objectives are rather general, and are expressed as 'to supply all the water needed for the country's development and welfare for all times to come.' As one moves down the hierarchy the criteria become more specific, and conflicting objectives appear. Generally, domestic supply has the highest priority, and the remainder is given to agriculture and industry. The primary criteria for evaluation of specific plans are: meeting demands, preservation of water quantity and quality in the sources for future generations, economics, environmental quality.

**Question 4:**

The severest constraints are: the limited water resource, budget, the need to supply water according to the national settlement plan, the (political) difficulty to reduce the water allocation to agriculture (in order to balance the demand with the limited supply, as the domestic demands grow).

These constraints, all of them, have been and still are the subject of debates and controversies. Even the first, which seems to depend on natural and 'objective' phenomena, is subject to discussion because one can allow over exploitation of the aquifers for some time at the 'expense' of future generations, and therefore the total resource constraint is actually a policy variable. The other constraints are obviously policy decisions, and are therefore open to a great deal of discussion, even in the context of a particular regional study and not only at the national level.

**Question 5:**

It is very hard to answer this question in the context of our multi-year multi-project case. Methods of analysis were developed, adapted and applied in various parts of the work. At times there was considerable disagreement on which method(s) to use, but this had in general a positive contribution to the ultimate outcome of the analysis. At other times it was quite obvious which method would be best.

Practically all of the known systems analysis approaches and techniques have been used, in one case or another.
3. Planning Stage 2: Data Collection and Processing

Question 6

Many data bases have been developed over the years, yet it is recognized that considerable uncertainty always remains. Some of the data collection, analysis, assembly and publication deserve special mention. Hydrologic data of surface water (flows, qualities) and of groundwater (levels, extraction, quality) are collected regularly on an extensive spatial and temporal grid. These data are published and made available to all planners. An official 'Water Resources Potential Book' is updated once every few years, and, once published, is a formal binding document for all plans. While it is recognized that this document does not constitute the ultimate final 'truth', it puts order in all planning work by establishing an official guideline.

On the demand side the situation is different. Exact data exist on past and present demands (monthly and annual quantities for all consumers) since water is allocated, metered and charged. Forecasts of future demands, in particular for new settlements and the increase in domestic use, are open to estimation and evaluation by planners, even though some binding national documents do exist.

A source of uncertainty in planning is the estimated budget that will be available to the water sector in general and to each project in particular, in the years to come. In recent years this uncertainty has been a cause for considerable difficulty in the planning phase, more so, for example, than any expected changes in cost data, interest rates, etc. Also net benefit from water used for irrigation is an important piece of information for planning. Data exist from a number of sources, but there are considerable differences between value given by the various sources (depending on their vested interest in this matter) so that no firm data are available.

Question 7:

Data is constantly collected, analyzed and assembled by the Hydrologic Service, Tahal and Mekorot on: hydrology of surface and ground waters, actual consumptions, expected demands, costs, benefits from irrigation. Still, for each plan formulation some additional data assembly and analysis is performed. Occasionally, synthetic data generation is also used.

Question 8:

OR techniques have been used by the Hydrologic Service to plan and operate the data collection networks, primarily of groundwater.

Question 9:

Assessment of data availability is performed on a regular basis by the agencies in charge, and therefore there is usually no need to deal with this matter explicitly in the context of a particular planning study.

Question 10:

Data analysis, using a variety of statistical methods, is carried out on a regular basis by the Hydrologic Service and Tahal, for the surface and ground water hydrology data.

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11:

A typical regional planning study requires between 1 and 2 man-years of systems analysts and supporting staff. Additional costs are primarily for several hours of computation time on a large computer.

Question 12:

Not relevant, since the studies are carried out by the institutions themselves.
Question 13:

No public participation in the normal sense, except that mentioned already in Question 2.

Question 14:

The alternatives are usually defined in a mathematical programming model by a set of constraints. Therefore there is an infinite number of feasible alternatives. Still, the constraints determine the range of feasible alternatives, and setting the constraints amounts to screening out some alternatives. The systems analysts formulate the constraints, and must therefore be careful not to impose their own fixed ideas on the plan. In a typical model there is a very large number (hundreds, even several thousands) of constraints, and some are rather intricate. The chance that anyone but the systems analysts themselves will detect misconceptions and/or errors in the constraints is very low. This puts a great responsibility on the systems analysts, and they must exercise a great deal of self-discipline and perseverance in checking and re-checking the constraints.

Mathematical programming models can determine the sizes of components which are present in their formulation - if allowed they can zero out values, thereby deleting proposed components - but they cannot 'invent' new components where such were not included by the analyst in formulating the model. Thus model formulation does contain some alternative selection. The analyst must therefore be careful to include in the model all reasonable alternatives, and not screen out arbitrarily such alternatives.

Question 15:

Decisions in Israel's water sector are made by the Water Commissioner. He has appointed several committees to aid him in this matter, so that each plan must pass through an elaborate checking and approval process. For important projects an ad-hoc steering committee is usually set up. It is the first level of plan evaluation, but its output must then go to the permanent committees, and ultimately to the Water Commissioner himself.

Trade-offs are sometimes expressed explicitly (in the model itself or in the evaluation process) and sometimes implicitly. Conflict resolution is by discussions in committees, ultimately by the Water Commissioner himself, aided by results of the analysis.

Question 16:

A full answer to this question would cover much more space than is allowed here. We shall try to answer in general, for the various types of constraints normally present in our planning studies.

(a) Hydrology and available water: These are rather well fixed. Some sensitivity analysis is usually performed, to explore the effect of uncertainty in our knowledge of the sources and of the stochastic hydrology.

(b) Demands: Some are imposed by the national development plans for settlement. Forecasts of urban demand growth are open to discussion and analysis by the planners. Agricultural demands almost always exceed available resources, so that little difficulty exists in assessing them.

(c) Economics: The budgetary constraint must be dealt with by parametric investigation, since it is usually unknown in advance. The same holds true for the interest rate.

Question 17:

Many models have been used over the years: optimization (LP, DP) and simulation (deterministic, stochastic). For planning purposes, the TEKUMA model (Schwarz et al., 1981a,b, 1982) has become the standard tool. It is a package of programs which includes the following components:
(a) A matrix generator. Given the basic data, it 'expands' it into the full coefficient matrix and writes it out an MPSX input file.

(b) Solution of the LP by MPSX.

(c) A report generator. Given specifications by the user it writes out the tables of the output in a convenient and useful form.

The LP model considers the following:

(a) A number of time periods over the planning horizon (e.g. 5 years, 10 years).

(b) Each period is represented by a year, divided into seasons.

(c) Several hydrologic conditions are considered, each representing a different level of water availability at the sources (e.g. dry, average, wet).

(d) Two types of water (e.g. potable, non-potable) are identified. Sources and links (pipes, channels) belong to one or the other type. Consumers may tolerate up to a given percent of either type in their supply.

(e) Over-year and within-year storage.

(f) Lower bounds on demands must be met. Consumers may be able to purchase more, depending on the cost of the water delivered to them and the benefit they can derive from using it.

(g) Decision variables are: capacity expansion in each period, annual and seasonal operation in the typical year of each period, of the sources and links.

This model has been developed at Tahal over the past years, and has been used to study the entire national system and several regional plans.

Question 18:

The models which have been used in the past, and the TEKUMA model as well, are always subject to a long and detailed testing and verification process.

We repeat here a comment made earlier. The systems analysts have an onerous responsibility to make certain that before any final results are generated with a model it is free of logical and data errors. If this is not done early enough in the study then more likely than not such errors will become apparent later, as results are studied for the final plan formulation, casting doubt on the entire study and rendering the modelling effort useless.

Question 19:

See answers to previous questions.

Question 20:

Disciplines participating in planning studies include: agriculture and irrigation, agricultural economics, hydrology, hydraulic engineering, water and sewage treatment, engineering economics.

5. Planning Stage 4:
Development of Final Project Specifications

Question 21:

See Question 17.

Question 22:

Cost-benefit analysis has been employed in specific design studies. In planning studies the objective is usually to minimize cost, since the level of supply and of service is imposed.

Question 23:

Explicit risk or impact analyses are not performed usually.
Question 24:

Multi-objective methods have been tried (Alkan and Shamir, 1980), used on a routine basis. More often, sensitivity analysis is used to explore the trade-offs between objectives.

Question 25:

See above.

Question 26:

Optimal solutions generated by models are used to formulate final plans, which are then approved via the process discussed in Question 15.

Question 27:

See Question 15.

Question 28:

Projects are all funded from the national budget allocated to the water sector, except some local projects in whose funding the consumers participate.

Questions 29:

No explicit study has been carried out to evaluate a specific part of a planning process. The analysis goes on almost continuously, and past plans are constantly under re-evaluation and modification.

6. Planning Stage 5: Project Design

Question 30:

Detailed design and drawings are prepared by other departments of Tahal. There is a close cooperation between the systems analysts and the designers.

References


PROMOTION OF MULTIPURPOSE WATER MANAGEMENT FACILITIES IN THE TIRNAVA MARE BASIN

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1. Introduction

Multipurpose river basin development, aiming at both flood control and the rational use of water resources, plays a significant role for the economic and social development of Romania.

Thus, since the '50s when the first national five years plans were in full progress, an increasing attention was given to the water problem, starting with the development of the hydropower potential.

Later, the comprehensive water resources management schemes were studied; during 1959 - 1962, the multipurpose water resources development plans for each river basin and for the whole country - Water Master Plan - were prepared.

The necessary methodological procedures concerning the outline of river basin development plans and the guidelines for solving the implied technical and economic problems were prepared within a close cooperation of the involved interdisciplinary specialists.

Water Master Plan served as a valuable base of subsequent five years plans for water resources development.

A systematic activity is implemented within the water resources management planning field consisting of periodical adapting of long-term forecasts and of framework river basin development schemes in connection with the social-economic development five years plans.

This activity, as well as the project/design planning activity, represents an appropriate framework to implement and develop the methodological tools including the system analysis techniques as a major component. The above-mentioned techniques are also applied when preparing and updating long-term reservoir operation rules as well as for supporting operation decisions of water resources system in the day-by-day activity.

Following the catastrophic floods of 1970, which damaged certain areas in the country, and based on the mentioned Water Master Plan, there was initiated the Multipurpose Comprehensive Development Plan for the Upper Mures river basin, the so called "Mures Project". This project examined the general framework of regional development and the related water resources management problems.

The wide variety of the problems, both technical ones -
hydrology, hydrogeology, geology, hydroengineering, water management, land reclamation - and those concerning economic, demographic, housing and social aspects, required the participation of Romanian personnel from many specialized governmental organizations in the country. An important support was from the UNDP, consisting of technical assistance by highly qualified U.N. experts and fellowship training programmes granted to Romanian specialists involved in the project development.

The development of the Mures Project gave a good opportunity to update, extend and improve the methodological tools used for river basin development problems and for the promotion of water resources management systems.

Tirnava Mare, as a subbasin within the Upper Mures basin was also analyzed for a multipurpose development, the major and more urgent problems being regional planning, population and economic objectives protection against floods, and low flow augmentation to permit water provision for population, industry and irrigation.

The studies concerning the feasibility alternatives for flood protection consisted mainly of:

- analyses of flood hydrological parameters under the actual conditions and for various assumed possibilities of rainfall-runoff occurrence and distribution;

- survey of experienced flood damage and determination of potential flood damages;

- economic feasibility analyses for the selection of flood control scheme.

Within the adopted water resources development scheme, storage reservoirs play the most significant role, an important reduction of maximum flow levels along the river being thus achieved. Embankment works, upon the waters controlled by reservoirs flood flow, were adopted only in limited zones, namely to protect human settlements.

The performed analyses showed a high effectiveness for the proposed flood control facilities, as the expected annual average damage will decrease to less than 4% of its value in the pre-existing situation.

Besides the hydroengineering works for flood control, i.e. embankment works, river bed regulation and detention/temporary reservoirs the river basin development scheme included also multipurpose reservoirs with conservation storage capacity for low flow augmentation in dry periods.

Now, after ten years from the Upper Mures Project start period, most of the hydroengineering structures in the Tirnava Mare river basin are already under operation or in an advanced stage of completion.

The planning process for multipurpose water management facilities in Tirnava Mare river basin is illustrated in the following, according to the adopted questionnaire.

2. Planning Stage 1: Project Initiation and Preliminary Planning

Question 1

In Romania, the framework of a planned development in the field of water has been initially defined by a Decree issued in 1953 regarding the rational utilization, management and protection of water resources. The Decree stipulated the promotion of a multipurpose water management and the conditions imposed for all the water related work.

On the basis of the mentioned Decree, there have been elaborated the first river basins multipurpose water management plans and in 1962
the long term water resources development plan for the whole country

Later on, for certain areas, as required, the water resources development schemes have been updated.

The promotion of multipurpose water management in the Tarnava Mare river basin observed the above-mentioned general line.

The solutions for protection against the floods and, for users' water supply have been established within an integrated long term analysis.

Thus, using our own experience in the elaboration of water resources development plans and with the assistance of U.N. - U.N.D.P., during 1972-1975 there has been prepared a comprehensive multidisciplinary development plan for the Upper Mures river basin, the so-called "Mures Project". This plan was a progress from the point of view of conception of the regional planning elements consideration, within the river basins development, as well as regarding the methods that have been used or developed.

The necessity of integrating water related works in a unitary conception of the complex management and comprehensive and rational use of water resources is underlined in the Water Act (Law) adopted in Romania in 1974. This Law states (in art. 4) the elaboration of a framework scheme for river basins development, as well as (in art. 30) that project documents for the hydroengineering structures, or for water related works, should take into account the stipulations of the framework water related development schemes.

The same Law states (in art. 36) that for hydroengineering or water related project documents there must be obtained the agreement of water management authority. The Law also states (in art. 37) that by the agreement of water management authority, the water users are obliged to achieve the works and to take necessary measures in order to avoid disturbing other uses and to prevent damages in the area.

The framework water resources development schemes, reviewed every 5 years, and the elaboration of the water management agreement for hydroengineering structures and for any other water related objective, constitute premises for solving the immediate as well as the future water management problems in a rational manner in accordance with their importance for the general development of the country.

Question 2

The coordination of activities for the development of the required studies in different stages and project documents, as well as the promotion of water related development facilities has been accomplished by the Permanent Executive Body of the Upper Mures Project.

The elaboration of the complex water resources management scheme and the necessary methodology improvement have been achieved by the Research and Design Institute for Water Resources Engineering (ICPGA).

The wide variety of problems, both technical ones - hydrologic, hydrogeology, geology, hydroengineering, water management, land reclamation - and those concerning economic, demographic, housing and social aspects, required the participation of Romanian personnel from many specialized governmental organizations.

An important support was from the UNDP consisting of technical assistance by highly qualified U.N. experts and fellowships training programmes granted to Romanian specialists involved in the project development.

Since the beginning of the Mures Project and throughout the
preparation of planning studies and project documents, for the main hydroengineering structures, the local authorities have been consulted. These supported the priority of solving flood protection for human settlements and the economic objectives, as well as in the provision of supplementary flows for population and industrial users.

Question 3

The Mures Project and the promotion of water resources management facilities in the Tarnava Mare river basin, as part of this project, have been initiated following the line of integrating the water management activity in the social-economic development of the country (see Question 1).

At the same time, the decision regarding the initiation of the project has been determined by the floods of 1970 which caused important damages to the populated centres and to the economic objectives in the area.

Question 4

In general, there have not been major restrictive constraints affecting the development of the project.

As a restrictive constraint, imposed by the local authorities due to some potential damaged localities in the Tarnava Mare major river bed, there should be mentioned the urgent requirement to increase by local works the degree of protection against floods in the principal human settlements. The dimension of those local works had to be conceived to ensure, together with the effect of considered flood control storage capacities, the required degree of security.

The achievement of local works (river beds training, embankment, and others) represents a transition solution achieving to a great extent the aim of protection against floods.

The problem has been solved through cooperation among specialists, local authorities and the decision-makers. Thus, in some areas where the minor river bed had become very narrow as a result of urban development in the past a severe systematization of the built area was necessary.

Some of the embankment and river bed regulation works have been completed in 1974 - 1975.

Now by the achievement of the principal flood control storage and detention pools, proper degrees of security against floods have been avoided.

Question 5

The existing methodology for the Water Master Plan, for the framework water related development schemes and for the planning of the water management system served as a starting point and the introduction of possible improvements during the project development has been decided.

The necessary improvements refer mainly to the extension and the refinement of mathematical models for flood occurrence, to hydraulic estimations, and estimations of water management from a quantitative and water quality point of view.

3. Planning Stage 2: Data Gathering and Processing

Question 6

Within the project there have been used besides hydrological data, data regarding flood damages, demographical data, and elements regarding the economic development of the area and regarding water requirements. These data are discussed with Question 7.

Question 7

Analysis of flood hydrological
parameters was performed in two ways: first, by processing the observed available data (a continuous observation period of 20 years supplemented with information on the most significant historical flood event from a period of over 100 years), and second, by mathematical modeling of rainfall - runoff process, for relevant scenarios regarding the rainfall distribution in various river basin areas.

The flood hydrographs and the peak flows, respectively maximum levels, were thus obtained for the natural flow regime and served as base input data in the feasibility analysis of the structural flood control alternatives.

As water resources data there have been used a series of average monthly flows for the period 1950 - 1970 considered as fitted for the estimation of water management balance regarding the water uses.

For the synthetic generation of hydrological data (as average annual flows and average monthly flows, with and without consideration of self-correlation) existing models have been adopted from relevant publications and were elaborated into computer programmes. The low degree of regularization of the examined storage reservoirs did not require the use of synthetic flow generation models for the water management estimations.

The data regarding water needs for irrigation have been determined for the period 1950 - 1970, as average monthly values using the potential evapotranspiration method and the soil water balance. A mathematical model for the synthetic generation of irrigation water need values on the basis of temperature and rainfalls data has been tried, but the results have not been satisfactory.

The analysis of flood damage started with the survey of flood damages experienced during the floods of May 1970 when on the Tarnava Mare there were recorded maximum levels close to 1% occurrence probability.

The distribution of damages along the river showed a major concentration in urban centres, the maximum weights belonging to industrial units (64% of total losses) and for substructures and residences (34% of total).

Based on the evaluation of the 1970 flood damages and on potential damages, gathered by inquiry estimations, for two flood levels of 5% and 0.5 - 0.1% occurrence probability, the "maximum level/peak flow - flood damage" relationships were determined.

The "damage - probability" functions could be obtained by combining the "flow - damage" and the "maximum flow - occurrence probability" relationships; furthermore the annual average potential damages were determined in the major areas for the given/existing situations and for the future development pattern of the areas, taking into account the economic growth and discounting the damage values.

Question 8

The data collection methods have been established on the basis of engineering analyses. As the study period for the average monthly flows, there has been taken the 1950 - 1970 period with more reliable data and with a sufficient length for the quantitative water resources - water demand balance.

Question 9

The estimation of the available data has been made on the basis of the analyses performed by the specialists and presented within a panel organized by the Permanent Executive Body of the project, with the participation of U.N. experts.
Question 10

Among others, in the analyses regarding the registered flood hydrographs in the subbasin, there has been used the simulation model of flood waves routing and composition, namely UNDA /1/, also used afterwards in the estimation of the flood control scheme alternatives.

4. Planning Stage 3: Formulation and Screening of Project Alternatives

Question 11

Roughly, for the formulation and screening of water management alternatives in the Tîrnava Mare River basin there have been used about 60 man-months and 300 hours of computer facilities (IBM 360 and ICL 1905).

Question 12

The promotion of multipurpose water resources development in the Tîrnava Mare River Basin, as well as the whole Mureș project, has been supported by the Romanian Government with equipment, financial means and computer facilities (see Question 2).

Question 13

As was mentioned in Question 2, since the initiation and along with the planning activity for the principal hydroengineering structures there has been permanent cooperation with the local authorities and other representatives of the public in the area.

Question 14

There have been examined 7 major groups of alternatives for multipurpose water management and a lot of subalternatives determined by hypotheses of socio-economic development, hydrological data (flood occurrence patterns), and technical parameters of the structures in considered alternatives of the water resources development scheme.

The alternatives were proposed by technicians/experts and established through discussions organized by the Permanent Executive Body - P.E.B. - with the participation of UN - UNDP experts within consulting missions.

Question 15:

The hierarchical structure of the decision-making process has resulted from the organizational and development pattern of the project, as mentioned in Question 2.

The preparation of the alternatives was made by specialized institutes and by the P.E.B. with the assistance of UN experts.

The technical options have been taken by the preliminary approval of proposed solutions at involved ministries in agriculture, water, forestry and regional planning problems.

The final decision was taken at governmental level that approved, for each hydroengineering structure (but taking into account the general framework, the technical solutions), the financing and materials means and necessary manpower.

The trade-off aspects have been treated by qualitative implicit estimations. Thus, for some storage reservoirs the requirements of the dam's construction and those concerning the storage/reservoir area did not fit, such that the examination of location alternatives was imposed. There have been preferred locations with more difficult conditions for the dam's constructions but more favourable ones for the storage area.

Question 16:

There are not additional mentions other than those of Question 4.
Question 17:

The development of the Mures Project gave a good opportunity to update, extend and improve the methodological tools used for river basin development problems and for the promotion of water resources management systems.

The mathematical models, largely applied within the project, were those of quantitative water management (for flood control and for the water management balance).

The UNDA mathematic simulation model and the associated computer programme /1/, based on the numerical integration of the Saint-Venant equation system, was applied along the whole development of the project to perform the analyses of the hydraulic and flood control parameters (reservoir routing, flood waves composition and channel routing).

This model, prepared and applied in Romania previously, has been refined during the Mures Project.

As the UNDA simulation model requires as input data a set of characteristic parameters representing in fact unknown quantities of the problem, the number of alternatives to be examined was too high. Moreover, due to the fact that the UNDA model being rather sophisticated, is computer time consuming, out of the numerous possible alternatives, only a few ones were selected for such a detailed analysis. The preliminary screening of alternatives was achieved mostly based on heuristic analyses and approximative/expeditious procedures.

The simplified simulation model PRAT was developed in this respect, based on less accurate computation procedures, but offering high efficiency as well as rapidity.

This model performs flood routing through reservoirs, or channels and flood waves composition as well. Computation procedures used within the simplified model are the Puls method for reservoir routing and Muskingum and Kalinin-Miliukov methods for river bed routing/8,18/.

The possible conjunctive use of UNDA and PRAT models is to be mentioned. As the input data for the UNDA model implies important technical and financial effort, the PRAT model is used to facilitate the selection of zones for more detailed analyses. On the other hand, when the UNDA model can be applied, that is very useful even in preliminary studies to help the calibration of the PRAT model parameters, an important increase of PRAT results accuracy being obtained. Therefore, it is more efficient to do preliminary screening for the selection of the alternatives to be detailed by UNDA model, a higher operativity in solving the problem and an important saving of computer time and funds being achieved.

In connection with the use of the mentioned simulation models a progress was achieved in preparing rainfall - runoff models/5,23/.

Besides the PRAT simplified simulation model, for the preliminary screening of structural alternatives (and therefore for the system parameters selection), a preoptimization model was experimented on, based on the separable linear programming algorithm /8/.

This model aims to find out the most favourable combinations of the local flood protection works in the damaged zones and storage reservoir capacity for flood waves alleviation.

The analysis is performed on the maximum flow in each zone to be protected, without taking into account the explicit behaviour of the system by time intervals within the flood wave.
Input data for the model are:

- cost functions (investment cost present value plus the sum of annual expenditures converted to present values) for local protection in each zone to be protected, depending on the maximum flow in the respective zone;

- cost functions (investment cost present value plus the sum of annual expenditures converted to present values) for flood waves alleviation by reservoirs, depending on maximum flow reduction in the reservoir site;

- influence of coefficients, expressing the reduction effect of storage reservoir on the maximum flow in each zone to be protected;

- maximum flow values in each zone to be protected, for the occurrence probability corresponding to the required protection level/degree.

The model results are the maximum flow reduction in the reservoir sites and the modified maximum flow values in each zone to be protected, minimizing the economic effort in storage reservoirs and in local protection works.

For the water management balance there have been used mostly existing mathematic simulation models examining in monthly values the behaviour of water management systems up to getting the desired parameters (the achievement of the necessary degrees for meeting water needs for different categories of users).

As related to the study of technical parameters of multipurpose water management systems, the simulation - optimization model SIMOPT /11/ and the associated computer programme were developed.

The SIMOPT model, representing an improved and extended adaptation of previous procedures developed by Ian King, A. Filipkovski and J. Kindler within the Vistula project (1969-1971) for the use of Out-of-Kilter network algorithm /15, 16, 28/, does permit, for example:

- the explicit analysis of water flow within the river basin/water management system;

- taking into account the water quality protection requirements, as a dilution flow condition, downstream the return from the water users;

- consideration, within the total storage capacity, of a variable conservative capacity during the year months, in complementarity with the flood protection one;

- computation the factual degree/probability of meeting the water management requirements, expressed as frequency, as duration and as quantity (volume) as well.

This model is now applied in 6 river basins or subbasins in Romania.

Within the project there have been prepared also mathematical models for water quality problems: one of them is a simulation model for thermic pollution, which was applied after some refinements,

**Question 18:**

All those mentioned models were tested within the project.

The calibration and verification, as a prerequisite for an efficient use of the models in the studied problem, needed in the case of the UNDA model detailed data concerning the topography and the nature of river beds (including long and cross profiles, and roughness, and data regarding the recorded flood hydrographs.

The UNDA model was improved within the Mures Project, and the achievement of the SIMOPT model needed adaptations and extensions of
other similar models, aspects mentioned within Question 17.

Question 19:
The final solution was established and approved for each hydroengineering structure taking into account its articulation with the framework plan.

The participation and the role of the technical experts, the decision-makers and the public were shown within Question 15.

Question 20:
By its nature, the project needed a tight cooperation between the experts of several fields: hydrology, hydroengineering, demography, housing, regional planning, water management.

The necessary structure has been provided by the participation in the project of the Water Resources Management Institute - ICPGA - and of other institutes related to the given problem.

The cooperation within the project showed the importance of an interdisciplinary terminology as well as the major role of the workshops in order to clarify and approach the positions of the participants involved in the project development.

5. Planning Stage 4: Development of Final Project Specifications

Question 21:
The final solution parameters were determined using simulation models, i.e. the UNDA model for flood control aspects and facilities and the water management balance models for the conservative storage capacity of reservoirs for the consuming water users.

The existing models, prepared in Romania before the Mures Project, have been improved during the project, as shown within Question 17.

As a base in the elaboration and the improvement of the mathematical models one may mention as more important the books and papers/23, 25, 29/ for flood control and /15, 25, 28/ as concerns quantitative water management balance computation.

The technical literature that was most used included the following:


The use of mathematical models for final project specifications needed about 20 man-months and 50 hours electronic computer time (IBM 360 and ICL 1905).

Due to its performances, the UNDA model is recognized as the model with the largest application in the development of parameters for flood control systems.

The water resources - water needs balance simulation models are also used, according to the examined problem, but for water resources management problems as regards the meeting of users' water needs, the SIMOPT model is largely applied because of the multiple aspects that can be accounted for and due to the high effectiveness of the
optimization algorithm used within the computer programme.

Question 22:

The investments recovery duration, the benefit-cost ratio and the internal rate of return were used as selection criteria for flood control alternative comparison.

All the mentioned criteria use, as base, the benefit values to be obtained by achieving the proposed flood control measures and the structural facilities.

Recognizing the difficulties in the estimation of direct and secondary flood damages, multi-criteria analysis is very useful, including sensitivity analysis for a range values of series of parameters and factors such as the discount rate, hypotheses on the rate of economic development in the zone, and the study period for which the economic efficiency analysis is performed.

Question 23:

We did not make any proper risk or impact analysis.

For the chosen floods control solution there were determined the maximum flows (levels) in the natural regime and in the developed regime (modified by works) for the exceeding probability of 5%, 1% and 0.1%.

As concerns the river basin development impact, in order to prevent undesired side effects, the provision of a minimum acceptable flow, downstream of the storage dams, was taken into account and soil erosion prevention measures and works in the storage watersheds were proposed.

Question 24:

The final solution was chosen on the elements and information given by the analysis made according to questions 21 – 23.

The trade-off aspects were mentioned at Question 15.

We did not make any multiobjective optimization analysis.

The participation of the decision-makers was presented at Question 2 and Question 15.

The organizational and the development pattern of the project constituted a proper framework and a favourable premise in preparing alternatives and for the decision-making process.

The mutual understanding and the cooperation between experts and decision-makers may help definitely the development of the planning process of multipurpose water resources management.

Question 25:

Explicit trade-off analyses were not made. One had in view measures and waste water treatment facilities of return flows from the users, and their costs in order to provide the required water quality parameters were evaluated.

The minimum acceptable flow, in river bed downstream multiple-purpose storage, could be provided by the transfer of the required amount of water for the users located downstream.

Question 26:

The utilised models helped to prepare the alternative solutions of river basin development. The final solution was established by the decision-makers and the technicians/experts, taking also into account some additional information. This was because the model input data (water needs, and evaluation of potential flood damages among others) are affected by uncertainty.
Questions 27 and 28

As shown in Question 15 the Permanent Executive Body organized the preparation and the decisions justification through the specialized institutes, and presented the solution to the involved ministries and for government approval for each structure separately, but taking into account its articulation to the framework plan.

The necessary investment funds, materials and manpower were insured by the approval of each solution.

Question 29:

The analyses of multipurpose water management in the Tirnava Mare river basin as well as in other river basins were made in 1980 when the river basin development framework schemes were up-to-date. In the Tirnava Mare river basin there were no problems of water shortages or flood damages, in the zones where the water management facilities were completed.

The periodical update of the framework schemes associated to with the five-year plans and the elaboration of the project documents constitutes a favourable framework for the introduction of methodological improvement - when promoting the new multipurpose water management facilities - adapted to the different specific cases.

During the most recent years, within several research works regarding the water resources development plans in the Tirnava Mare river subbasin, supplementary analyses were made concerning some intercorrelation aspects, such as, for example, the following:

a. Quantitative water management - water quality protection.

The necessary dilution flows within the river beds to meet the required water quality standards according to existing regulations were considered as the starting point.

The analysis was focussed on the influence of the above-mentioned dilution flows upon the reservoirs operating regime (behaviour) and upon the actual degrees of meeting quantitative water demands.

The demands obtained in this way serve as a basis for performing comparative analyses of water quality control alternatives for each considered zone e.g: waste water treatment at upstream water users, decrease of raw waste load in return waters by intervention in technologies at upstream water users, water treatment at analysed water users, and increase of the dilution flows within the river beds by an appropriate reservoirs operating system.

b. Improvement of water-energy trade-off in a thermo power plant

An analysis was performed on the possibility of decreasing the recycled amount of water within a cooling circuit by increasing the installed capacity of the water supply system, taking into account the river flow regime variation as modified by the new proposed reservoirs.

The results obtained in this way serve as a basis for examining the economic opportunity of promoting the modernizing of the works of water supply system, taking into account the necessary costs in the considered modernizing alternative versus the energy saved in recycling the cooling water.

6. Planning Stage 5: Project Design

Question 30:

The design documents (project design) have been achieved by specialized groups of the same institute - ICPGA - involved in the elaboration of the river basin development scheme and insuring the development of stages 1 - 4.
The connection between the multipurpose water management experts and hydrotechnicians (hydraulic engineering) experts became permanent, when the two groups were establishing the functional elements of the designed structural facilities.

Thus, related elements (e.g. the water intake and the spillway and outlet facilities of storage reservoirs) had to be conceived so that the could take into account the operation rules, to provide the for achievement of water management parameters adopted to justify the promotion of the project.

System analyses techniques and procedures are applied nowadays on an increasing scale within ICPGA (The Research and Design Institute for Water Resources Engineering) and other agencies (institutes) related to water field activity, as well as within the local river basins authorities when promoting the water resources systems and establishing their long-term and real-time operation rules.

Thus, the following techniques are used in the planning activity to establish the design parameters of the water resource system:

- the BICAD computing programs package (Dulcu 1978) is used to create, maintain, update and operate the data base of water use inventory; it is applied nowadays within four of the total of nine river basins;

- the more sophisticated UNDA model (Amaftiesei 1976), applied in almost all the basins, and the faster, simplified model, PRAT, applied in 20% of the river basins, are used for flood control analyses;

- the simulation GRINGO, HOMBRE and ARTIZAN (Amaftiesei 1984) models, used to compute water resources-water demands balance, are applied in many river basins in accordance with the kind of the analyzed scheme;

- the simulation-optimization SIMOPT model (Dima, Visan 1980) used in any kind of scheme configuration in order to analyze the multipurpose water resources systems is implemented in seven basins and subbasins and will be progressively also applied for all the other river basins.

Concerning the problem of storage reservoirs and river bed sedimentation as well as the water quality regime including eutrophication, there were developed or are being experimented with mathematical simulation models in order to analyze the reservoir technological and operational characteristics.

For a better assessment of the water resources systems performances (outputs) and their behavior peculiarities, the main principles on global reliability were stated, taking into account not only the hydrological events (almost exclusively used nowadays) but the stability, functionality and other involved aspects as well (Dima 1978).

The use of multiobjective-multicriteria analysis techniques is one of the water management specialists' priorities (Solacolu, Ceachir 1978, longulescu, 1986).

When preparing the long-term operating rules in WRS planning activity as well as for the periodical updating of these rules along the WRS life period, simulation models (e.g. GRINGO, HOMBRE, ARTIZAN, UNDA, PRAT) and simulation-optimization models (i.e. SIMOPR) are used.

The random feature of most water resources characteristics as well as of some water management requirements oblige us to achieve in the WRS day by day operation such a regime of storing or discharge water that allows a rational trade-off between the updated long-term operation rules and the system's momentary (actual) conditions (Predescu 1982).
The preparation of operating decisions is achieved within a continuous iterative analysis feedback process (Dima, Cadariu, Visan, 1980) where the analysis techniques for defining the system's state play an important role.

The techniques used refer to explicit procedures of classic type (abaci, diagrams, preestablished operation alternatives) as well as mathematical models selected according to the problem in question.

The simulation-optimization ALOC model based on the Out-of-Kilter algorithm, is used to develop the monthly and quarterly operating plans of the multipurpose reservoirs.

A dynamic programming model minimizing the users' operation costs was developed for the optimal allocation of water resources among water users in a river zone (Parvulescu 1972).

Rainfall-runoff models (Serban 1984) are applied for real-time forecasting of water inflows at WRS entering points.

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APPLICATION OF SIMULATION TECHNIQUES IN WATER RESOURCES PLANNING IN THE GERMAN DEMOCRATIC REPUBLIC

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1. Increasing Complexity in Water Management

The developments in the last decade have in particular shown that it becomes more and more difficult in all parts of the world

- to satisfy municipal, agricultural and industrial water demands in the required quantity and/or quality

- to protect water resources against pollution

- to provide a sufficient flood protection.

The number and variety of water users and of pollution sources are steadily increasing and so are the requirements for a higher reliability of water supply (in quality and quantity) as well as for flood protection.

In many cases conflicting problems arise which can be solved only by a centralized planning of appropriate measures for rational use of the available water resources such as reservoirs, water transfer channels or pipes, waste water treatment plants, levee systems etc.

As these planning procedures have to consider problems and conflicts arising from the increasing complexity of water resources systems management, acceptable solutions can be found in more and more cases only by the application of mathematical models and advanced system analysis techniques. (Cohon and Marks 1975, Haimes et al. 1975, Haith and Loucks 1976, Major 1977).

This paper is related to problems as mentioned above, i.e. to multiobjective optimization of water resources management in river basins regarding multipurpose water usage and reservoir control aspects, with special regard to water quantity.

2. The Special Importance of Simulation Techniques in Water Resources Project Planning in Complex River Basins

In the selection of a modelling approach or systems analysis technique for the solution of the before-mentioned problems two basic questions have to be answered:

(a) Is a direct optimization desired or are the trade-offs of primary interest which result from different planning and control strategies?

(b) Should the analysis be based on selected critical periods, e.g. on observed historical low flow periods, or on sets of generated longer time series of the hydrological state variables expected in the planning period?
According to international developments there is a declining trend in the GDR in the application of direct optimization techniques (question a), and planning studies based on selected critical periods (question b) are only accepted as a pre-investigation of more complex modelling projects, or in cases where the modelling approach cannot be applied (because of a lack of time, research capacity....). This means that simulation techniques using sets of generated time series of hydrological input variables are generally preferred in the GDR, particularly for the derivation of optimum design alternatives and optimum control strategies for multipurpose reservoir systems.

The main reasons are:

(1) In most cases direct optimization techniques (linear, dynamic programming etc.) can be applied efficiently only for determined selected reference conditions (e.g. an observed or given critical period). This leads immediately to the question for the optimum solution in other more or less critical periods (see e.g. Shiao and McSparran 1971).

(2) As a result of applications of direct optimization techniques in the GDR, e.g. to determine an economical optimum structure of a water distribution system (Forner et al. 1980) or to optimize the control strategy of single reservoirs (Schramm 1981), it turned out that the calculated optimum served only as an orientation while political, territorial and water management aspects were taken as the main factors in decision-making (sufficient reliability of water supply for main users, etc.). Similar experience has been made in the application of utility theory, which is based on a unified evaluation of all aspects to be considered in the optimization (social, political, environmental, etc.) (Keeney et al. 1976).

(3) The application of explicit stochastic optimization techniques leads to serious problems in the case of systems with several reservoirs, and the chance-constrained programming does not fulfill all requirements (Palmer et al. 1979).

(4) The GDR is one of the European countries where water resources are relatively scarce and in multiple use (Dyck et al. 1980). Low flow and flood flow periods occur subsequently with typical persistency and cluster effects:

* subsequent longer low flow periods with significant deficiencies in water supply for a number of water users

* sequences of major and dangerous floods.

Therefore the control strategies, especially for larger reservoirs, have to take simultaneously into consideration the maximum possible recharge of water for low flood periods and also the requirements of flood protection for dangerous floods which can occur in the same period. That means that low flow periods and floods have to be considered in the simulation process in a realistic manner concerning their time structure, magnitude, sequence, etc.

(5) Water resources engineers and decision-makers in the GDR have expressed their primary interest in results on the efficiency of considered planning and control strategies. This especially concerns information on trade-offs in the reliability figures for all water users,
in hydrological characteristics on the flood regime, in water quality etc. Preferred is information in form of probability distribution functions, cumulative frequencies, etc.

(6) Information on economic effects obtained from cost-benefit analyses, cost-and-damage-analyses etc. is appreciated and often requested as a supplement, but it is never taken as the only basis in decision-making.

The aspects mentioned under (2), (4), (5) and (6) have particularly initiated the development of an efficient computerized long-term simulation technique (Schramm 1975) which is based on the Monte-Carlo-method similar to that introduced by Thomas and Fiering (1962), Svanidze (1984), Hufschmidt and Fiering (1966). It uses synthetic time series of the hydrological input variables, allows for a computation of numerous planning and decision alternatives and provides comprehensive information to support decision-making. In the following some special features of the above-mentioned simulation technique are briefly reported and some important results and application experiences presented.

For about one third of the territory of the GDR individual river basin models of that type were introduced and have been regularly applied for long-term balancing of water demands and available water resources and to select optimum long-term planning and control strategies for the river basin system (Gruenewald et al. 1977, Becker et al. 1978, Riechert et al. 1979, Both, Kozerski 1980, Dietz, Boehme 1980, Lehmann et al. 1981, Schramm 1981). The successful application of the developed simulation technique may be explained primarily as follows:

* The simulation algorithms of the models are clear and understandable for the model users and the complex conditions of water resources use and management in extensively used river basins can be represented more realistically than in applications of direct optimization techniques.

* The results provided by the model clearly reflect the effects of a given control measure (decision alternative). The confidence of the decision-makers in the model is particularly confirmed by the fact that results obtained for simple decision alternatives meet their experience.

* There is no a priori restriction of the decision range because the model does not require preselected criteria for the computation (e.g. a distinct objective function or assumptions of the decision-maker on preference structures etc). It enables the decision-maker to extend step-by-step the desired information on the system behaviour, the efficiency of new water structures, changed control strategies, the trade-offs, etc. according to the progress of the simulation.

* The information received can be used also as a basis for a collective decision-making which includes water users and other interested authorities.

These conclusions are confirmed by a publication of Kindler (1981) in which he illustrates the step-by-step progress in an interactive computer aided decision procedure referring to a definite selected hydrological situation.
3. Short Summary of Characteristics of the Advanced Version of the Simulation Model

The simulation technique mentioned before has been systematically improved during the last years. The main objective of this research work was to set up a program system which can easily be adapted to any given river basin and which allows for a consideration of

* various planning and management alternatives

* different water demand figures (including seasonal variations or trends over a longer planning period)

* long observed or synthetic series of hydrological input variables characterizing the available surface water resources.

The advanced version of the program system has self-adapting features so that within a single computer run the specific sub-programs and algorithms for a given river basin are automatically generated according to the specific input data (Kozerski 1981). The program facilitates

(1) the treatment of any given river system

(2) the investigation of different system structures and control strategies

(3) the optional use of observed or synthetic time series as hydrological input variables

(4) the specification of the form of representing the simulation results.

The basic components of the advanced program, their interconnections and integration in the decision process are represented in a general form in Fig. 1. Supplementary information on important measures considered in the planning process is given in Fig. 2.

Main parts of the program are:

(A) the stochastic simulation model for the hydrological input characteristics which define the available water resources

(B) the deterministic water management model which simulates given strategies of water allocation, reservoir operation etc. in the river basin, and provides the registration of water supply deficiencies, resulting damages and other state conditions of interest for the final statistical evaluation.

An additional component is

(C) the program for the representation of the model output data.

The last mentioned program and the data dispatching procedure were designed on the basis of special data identification, checking and preprocessing procedures which enable any given river basin system (or system structure) to be modelled by simple input data specification (instead of software development as required in previous models.) It should be mentioned that those principles are on-line with recent international trends.

Other essential principles in the program development were:

(1) The deterministic water management model (B) was completely separated from the stochastic simulation model (A), which generates intercorrelated time series of the required hydrological input variables (e.g. monthly averages of streamflow). These input variables are stored on magnetic tape and can be read into the main storage for each actual computation.

(2) The generalization of the deterministic water management model (B) which simulates the processes of water allocation, utilization and management in a river basin, including reservoir operation, was achieved by means
of typified algorithms for the various operations occurring in the system.

(3) The program for the representation of the computation results (C) was also generalized with regard to two forms of data lists (tables) printed by the computer.

Because it is the performance features (general applicability, flexibility, etc.) that makes the advanced model version attractive for practical application, some essential details will be described briefly in a later chapter.


It is quite obvious that the reliability of the hydrological information used in the planning process is extremely essential for the reliability of the results. Errors in the hydrological input information will affect all subsequent steps of the planning process and can lead to inadequate decisions (wrong design of new structures etc.). Thus new orientations are needed during the International Hydrological Programme for future research in this field due to the following general problems in hydrology:

(i) The hydrological systems are increasingly affected by human influences. Hence, information on the available water resources and on the hydrological regime derived from existing data series cannot be simply extrapolated into the planning periods to be investigated.

(ii) Long-term climatic changes modified by increasing human impacts can also influence the availability of the water resources.

Therefore it will become more and more necessary to compute the available water resources by means of hydrological models of river basins from meteorological input fields (precipitation, evapotranspiration) taking into account the effects of expected climatic changes (trends, etc.). As generalized techniques for such an approach were not available the approved simulation technique based on the Monte-Carlo-principle as introduced by Schramm (1975) was applied. It generates time series of intercorrelated hydrological input characteristics of any desired length, e.g. 20 sets of 50-year records of monthly river discharges, as stochastic, multidimensional, unsteady, transformed normal-distributed Markov-process of higher order (Schramm 1975).

In some countries the approach was argued against as follows: the generated time series cannot supply more information than the shorter observed ones which are taken as the basis for the synthetic generation; observed single extreme events are inadmissably extrapolated into the planning horizon; therefore the use of the observed records for the planning investigation seems to be the best solution. As reply to these arguments the following may be said:

(1) Probability distributions of the hydrological, water resources related variables, e.g. river discharges, have to be based on sufficiently large data sets in all ranges to be considered. This is only guaranteed if longer time series are available.

(2) The application of the multidimensional generation technique ensures that the information involved in the longest observed records of the river basin under consideration is generalized. In addition to this the empirical distribution
functions and those received from the generated time series can be critically reviewed and compared with those derived from available long records of other stations, in order to avoid errors of the above-mentioned character.

(3) Long generated time series of discharges which adequately reflect the statistics of the real process include a larger variety of critical events or sequences of such events (deficiency periods, floods, etc.) than the observed records.

The wide practical application of the approved simulation technique has confirmed its practical efficiency.

5. Advanced Version of the Simulation Technique

The basic principles of the advanced version of the simulation model for water resources systems management which may be applied also for other purposes are described in another publication (Kozerski 1981). Here only a short summary should be given:

(a) To describe the configuration of a given river network all balance points and system elements along the rivers (location of water withdrawals and releases, of reservoirs, etc.) are denoted by decimal numbers (see Fig. 3 and col. 1 of Table 1). This notation allows one to refer to any existing river system classification, and to include or exclude intermediate balance points without any redenoting of other points. For internal purposes of the computer program the decimal notation is automatically transformed into an integer numeration (see Table 1). For each balance point the next downstream balance point is specified so that the network configuration is entirely defined by the single vector NEXT (K); (NEXT(K) = - 999 characterizes the closing profile). This vector is then also used as a "downstream operator" which organizes a downstream computation by means of the simple operation K' = NEXT(K).

(b) Accordingly a generalized description for all water uses was introduced which allows one to specify (see Table 2 and Fig. 5):

* the location of water withdrawal (PE) and return flow (PR)

* the related quantities (E, R) as constant or seasonally varying values (e.g. monthly).

* preference numbers (Z) defining a priority sequence of the users (smaller preference number denotes higher priority).

(c) The process of water resources utilization and management is simulated in each computational step as follows:

- Reading of the required hydrological input variables (e.g. uninfluenced discharges) from a data storage unit.

- Allocation of water to all users according to their demand and priority, the available water resources and the release of water from reservoirs, if necessary.

- Calculation of the resulting state conditions (actual water supply, reduced discharges, actual reservoir storages, etc.).

- Registration of these state variables (cumulative counting) according to a specified list of preselected variables and events to be analysed.

Water withdrawal and return flow may be located at the same balance point (e.g. N 204 in Fig. 3) or at different ones.
(e.g. N 102). A user can be subdivided into several user elements (portions of water use of different importance which are specified by different preference numbers, e.g. splitting of N 103 into the elements N 103.1 - the so-called basic demand with preference number 50 - and N 103.2 - the residual demand with preference number 180). The sequence of users in the allocation procedure is controlled in each time step by the preference numbers (from smaller to higher ones), e.g. the system of users given in Table 1 is computed in the following sequence: N 103.1, N 305, N 102, N 103.2, N 204.

(d) Reservoirs can be described analogously in their location, capacity, conservation volume, flood control volume, etc. The use of the reservoirs for water supply is specified by "release elements", which also have a preference number. Here a number Z = 100 means that from the corresponding reservoir zone water releases are allowed for all users of higher priority (in Table 2 those are N 102, N 103.2, N 204). Thus, by means of a few data manifold reservoir - user relations can be described including subdivision of the reservoirs into sub-zones. If the computed storage volume exceeds the conservation zone volume then increased releases are computed according to the capacity of the river bed downstream of the reservoir.

(e) Another facility of the computer program (optional available) enables the user to integrate specific algorithms (so-called "dynamic elements") which are not covered by the standard elements of the advanced model (including calls of external subprograms in FORTRAN or ALGOL, and to consider state dependent modifications of the allocation procedure (as e.g. smaller quantities of water withdrawals in case of exceedence of a given limit discharge, etc.).

The desired flexibility and simplicity of the data output program was analogously achieved by defining two basic types of registration:

- type 1 - registration of any desired variables (e.g. discharges at balance points, withdrawals of users, etc.) and output of probabilities of exceedence of definite discharges in the form of data lists as shown in Table 3.

- type 2 - registration of the first month and of the duration of the critical events or conditions (e.g. duration of exceedence of given limit discharges, duration of definite deficiencies in water supply etc.) and output of the data lists.

An example of a type 1 - output for a lowland river in the GDR is shown in Table 3 (probabilities of exceedence of the discharges listed in column 1 of Table 3). The typical seasonal variation of the discharges can be clearly seen. While the discharge in February always exceeds 19 m³/s (100% probability of exceedence) the monthly discharge in August is within the investigated 100 years period twenty times below 1 m³/s (only 80% probability of exceedence). A monthly minimum discharge of e.g. 6 m³/s can be guaranteed here only by means of additional reservoirs or water transfers or, when the small summer discharges are caused e.g. by irrigation water losses by modifying the allocation strategy or by changing the priorities. The outputprint of similar probability lists can be specified for water supply deficiencies of any water user of interest, for storage volumes in reservoirs etc., as well as for durations of critical periods (type 2).
These tables are directly used for decision-making or for plotting to illustrate the trade-offs of conflicting objectives as in Fig. 4. Fig. 4 was derived in an earlier investigation for the Rappbode reservoir system with a total storage volume of 108 Mio m$^3$ (Becker et al. 1978).

The upper part of the figure illustrates the decrease of the reliability of drinking water supply with increasing drinking water withdrawal. It is further remarkable that this decrease is much smaller if the drinking water supply has a higher priority than the release of reservoir water for low flow augmentation (Curve 1).

The lower part of Fig. 4 illustrates the decrease of the reliability of drinking water supply with increasing flood control volume (Curve 1) and the according decreases in flood risk (Curve 2).

On the basis of Fig. 4 a control strategy for the reservoir system was finally defined which is accepted by all interested authorities and which in this sense represents an optimum.

6. Simulation of Floods for the Consideration and Planning of Flood Protection

The most dangerous phases of floods often occur during a few days or even hours, particularly in small and medium mountainous river basins. Therefore a simulation model which works on a monthly basis cannot adequately take account of the real flood risk (peak flows, duration of inundation etc.) and other approaches have to be applied for flood investigations. After a first attempt of distributing daily flows around the generated monthly mean flow by means of simple average distribution functions (Krippendorf, Schramm 1970) the following technique was developed and applied (Becker, Kozerski 1976).

Typical dimensionless flood hydrograph patterns (daily flows) were derived from a larger number of observed floods. These were then used to calculate daily flood flows in months the generated mean flow of which was identified as influenced by a flood. The particular flood flow pattern was selected by a random experiment (urn experiment).

A result obtained by the application of this technique for the Saale reservoir system is shown in Fig. 5. It indicates that

* an increased flood risk is given during February, March and April, despite an increase of the flood control volume by 15 Mio m$^3$ from November until March, as shown in Curve A (further increases of the flood control volume cannot be accepted because of the decreasing reliabilities of water supplies during the summer).

* an efficient release strategy for the flood control volume before and immediately after a flood can remarkably reduce the flood risk from February until April (Curve B instead of C in Fig. 5).

As next step a stochastic simulation technique for the direct generation of daily flood flows within a long-term simulation model has been developed and applied (Gruenewald et al. 1977). This technique is described in a special paper (Becker et al. 1979). The representation in the lower part of Fig. 4 is a result of the application of this technique for the Rappbode reservoir system.

In cases of separate planning of flood protection measures, i.e. without simultaneous consideration of water supply problems, a separate simulation of single flood events is acceptable. An example of application where about 300 flood hydrographs were calculated from synthetically generated 2-hour-rainfall data by means of deterministic river basin models is also described in the above-mentioned publication (Becker et al. 1979). One result of this
application (Fig. 6) shows that the reduction of flood peak flow by an uncontrolled reservoir is strongly discharge dependent, and that therefore the investigation of a selected flood (e.g. a design flood) is not appropriate. The results cannot be extrapolated to other flood events.

This underlines the necessity of investigating a large number of events, of generated time series of streamflows etc. as explained in Chapter 4.

7. Conclusions

For the planning of water resources systems design and management the application of simulation techniques which use stochastically generated time series of water resources characteristics in a deterministic water management model has been widely accepted. The advanced version of this type of model can easily be adapted to a given river basin by data specification alone. This is accomplished through automatic generation of the specific subprograms for the river basin to be modelled. To facilitate the processing of a series of management alternatives (typically differing in a few numerical parameters from one another) the computer program package allows for an easy input data modification which avoids the repeated input of a large number of data cards. It can be said that the model is readily available for practical application.

The flexibility and simplicity of the advanced model and the fact that the results of the computations are provided in the form of probability distributions of selected water resources characteristics for all months of the year (e.g. probabilities of exceedence of given limit discharges, supply deficiencies etc.) are considered as main reasons for the wide practical application of the model for river basins in the GDR.

References


A. Stochastic simulation model of the available water resources

Separate stochastic generation of time series of hydrological input characteristics for planning process (e.g. sets of 100 years records of monthly rivers discharges)

B. Deterministic water management model (repeated application for planning alternatives of interest)

Detailed balancing of the available water resources (as pre-generated) with water demands and other requirements, and allocation of water resources from reservoirs according to given control strategies, user priorities, etc.

Registration (in each computational time step)

C. Final statistical interpretation, evaluation and printing of the simulation results for each planning alternative

D. Decision making process

Analysis of the results of the computations with the decision makers

Set up of new alternatives of water resources management and allocation (if required) in coordination with the water users, decision makers etc. (including new system elements, modification of control strategies, technologies of water use, etc.)

Data specification for additional model runs

Decision making on the optimum system design, water resources allocation and management

Fig. 1 Main components of the planning process of water resources system design and management in river basins by means of simulation techniques.
Fig. 2.: Important Elements in Water Resources Systems Planning and Management

A. New water structures

- Reservoirs
- Water transfer channels and pipes
- Flood control structures
- Water treatment plants
  etc.

B. Changes of control strategies for the existing and for planned water structures

- Control of reservoirs, water uses, water transfers, etc.
- Installation of more efficient real-time forecasting and control systems

C. Alternative technologies of water use

- in industry
- for irrigation
- for public, environmental and other purposes

D. Alternative allocation of water resources in regard of

- priorities
- economical aspects
- social, environmental and other aspects
Fig. 3 Schematic representation of a river network with balance points (P), users (N) and reservoirs (S)
Fig. 4 Reliability of drinking water supply $R_s$ and possible flood damages in dependence of the
a) amount of drinking water supply
b) flood control volume
Fig. 5 Long-term flood risk below the Saale reservoir system for a definite flood control volume (curve A)
Fig. 6  Probability distribution functions of flood peak flow at a river cross-section (75 km²) for uncontrolled and controlled conditions.
**Table 1:** Description of the configuration of the river system in fig. 3.

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<th>Internal Index K</th>
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**Table 2:** Description of some users in the river basin of fig. 3.

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\(^x\) Remark: Smaller preference number Z means higher priority
### Table 3: Probabilities of exceedence of given discharges in a lowland river of the GDR (in Percent)

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