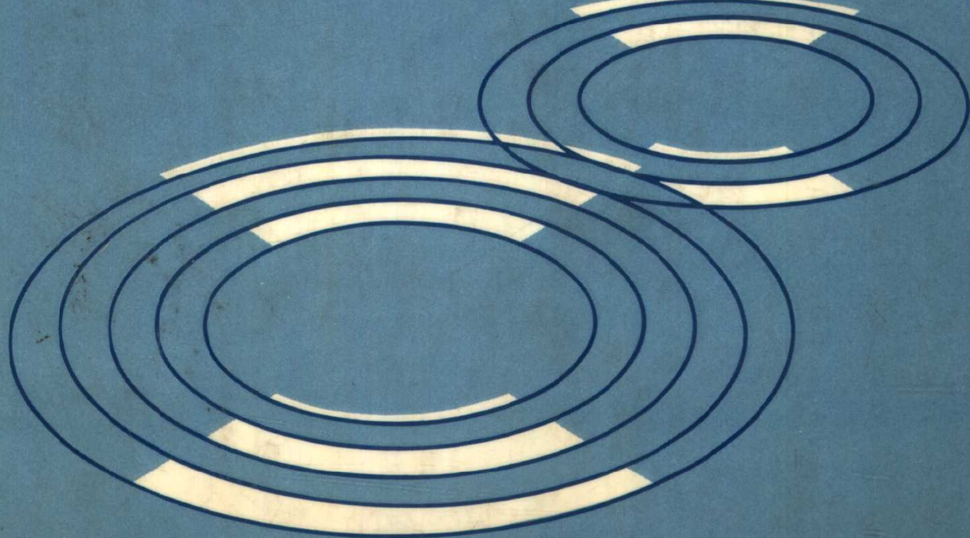
WATER RESOURCES

Planning and Management



Otto J. Helweg

WATER RESOURCES
Planning and Management

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John Wiley & Sons
New York   Chichester   Brisbane   Toronto   Singapore

Library of Congress Cataloging in Publication Data:

Helweg, Otto J.
Water resources planning and management

Includes index.
1. Water resources development. 2. Water resources
development--Planning. I. Title.
TC409.H44 1985 333.91'15 85-5305
ISBN 0-471-04770-8

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

WATER RESOURCES
Planning and Management

To Virginia

PREFACE

The purpose of this book is to introduce the major topics of water resources planning in one volume. It is designed primarily as a university text but should also be of interest to practicing engineers, planners, environmentalists, and administrators. Comprehensiveness and breadth are emphasized, with footnotes and bibliographies provided for the reader desiring more depth. Numerous solved examples reinforce and introduce material in the text, and the collections of selected problems at the end of chapters are designed to simulate planning studies. Additional guidance is given in an instructor's manual.

This book assumes a knowledge of elementary hydrology and mathematics (primarily algebra). The text uses economics and systems analysis but provides appendices for those who require a brief introduction. Although this text is written from an engineering perspective, the technical and mathematical material has been simplified in order to make the book useful to nonengineers. Throughout, the basic principles presented are applicable to both developed and developing countries.

Although water resources planning courses have been offered in universities all over the world for many years, until recently no text has been written specifically for this subject, even though the National Water Commission report and the Water Resources Center's *Principles and Standards* provide much of the necessary information. Other books with similar titles emphasize water resources systems analysis, water resources engineering, or water resources economics and are not designed for a general water resources planning course. This book should complement these other texts because it is designed to integrate their emphases into the broader context of water resources planning.

This book considers planning as the umbrella under which systems analysis, economics, and other such disciplines may be carried out. Planners must be more than optimizers (although they should optimize), and they must do more than maximize net benefits (although they should also do that). Planners must be able to integrate all these tools to achieve the best possible future with limited resources.

To achieve such an integration, many nontechnical subjects have been included here, some of which might seem more appropriate in a sociology text. Nevertheless, it is increasingly necessary for water resources planners to utilize nontechnical subjects because they, more than engineering analysis, may determine the success or failure of a planning effort.

ACKNOWLEDGMENTS

Many persons have contributed to my knowledge of water resources planning, and others have given me the needed encouragement to write this book. Much of the good and none of the bad in the following pages is due to them.

John Dracup first introduced me to water resources at UCLA. Victor Koelzer at Colorado State University showed me how water resources planning should be conducted after I had been doing it for some years (making many mistakes). Also at Colorado State, John Labadie attempted to instill mathematical rigor, while Neil Grigg taught me not to lose sight of the real world. I have also benefited from frequent contact with the U.S. Army Corps of Engineers and the Hydrologic Engineering Center (HEC), as is evident from the amount of material I have borrowed from these sources. I am also indebted to other colleagues from the U.S. Geological Survey, Bureau of Reclamation; the Water Resources Center; and the Civil Engineering department at the University of California, Davis. The latter two have given resources to assist the project.

My wife, Virginia, and my sons, John, Mark, and Steven, have been patient during this task and have provided me with love and support. Virginia spent many hours typing notes. The first draft was finalized while I was at the Punjab Agricultural University on a United Nations assignment. The faculty there were stimulating and understanding as I strove to complete this task during my evening hours. Special thanks are owed to Ved Parkash Chhabra, himself an author, who worked night and day to meet the deadline of my departure; to William Charlie; and to Robert Hinks, who reviewed the manuscript. Peggy Lerch, Kelly Carner, Marian Cain, Holly Chamberlain, and Jean and Kevin Roddy all helped enter the manuscript on the word processor. Dan Flanagan, the manuscript's copy editor, deserves much credit for making the book as readable as it is. His attention to detail caught many errors. The final draft was completed after I joined Texas A & M University and was assigned to establish the Water Studies Center at King Faisal University, Saudi Arabia. I appreciate the support of both institutions.

Otto J. Helweg

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CHAPTER 1

INTRODUCTION

This chapter traces the historical development of water resources planning, then describes it in its contemporary setting, especially as it relates to engineering activity. Although it is a crucial element of life, planning as a discipline is a relatively recent phenomenon. Along with urban and transportation planning, water resources planning has become a highly important field of study as increasing development and population pressures have come to bear on finite water resources.

1-1 HISTORICAL BACKGROUND[1]

Water resources planning is as old as civilization itself. Perhaps the earliest and certainly the longest-lasting flood warning system was that of ancient Egypt. Records dating from 3500 B.C. are available, either directly or by inference. From the beginning of recorded history, Egyptian engineers kept track of river stages by reading water levels on a device called a Nilometer (Figure 1-1). If the readings on the Nilometer showed dangerously high levels, fast rowers were sent downstream to warn residents to vacate low-lying areas.

[1]This section draws on A. K. Biswas, *History of Hydrology* (Amsterdam and New York: North-Holland and American Elsevier, 1970).

Figure 1-2 shows the time line of important events in water resources history, with time on a log scale. As with advances in other areas of human knowledge, many false starts punctuated a wide variety of acknowledged advances in the field. The hydrologic cycle was guessed at by some, but in the main there was no broad consensus about the relationship among the elements of the cycle of natural waters until the seventh century A.D. Workers were left to speculate.

Measurement of stream flow is certainly one of the fundamental calculations of water resource management. It appears that Hero of Alexandria was the first to put forth the concept that discharge equals velocity times cross-sectional area. This important discovery was ignored for almost 16 centuries, until it was independently arrived at by Benedeto Castelli (1577–1644), the founder of Italian hydrology.

Probably the earliest water supply system—parts of which are still operational—was the Roman network of aqueducts. The engineer who deserves the credit for this stupendous success was Appius Claudius Crassus, who completed the task in 312 B.C. Rome also had the first municipal sewer system, which was designed only for storm drainage; waste was not disposed in it for several hundred years.

During the 17th and 18th centuries, several European groups interested in the advancement

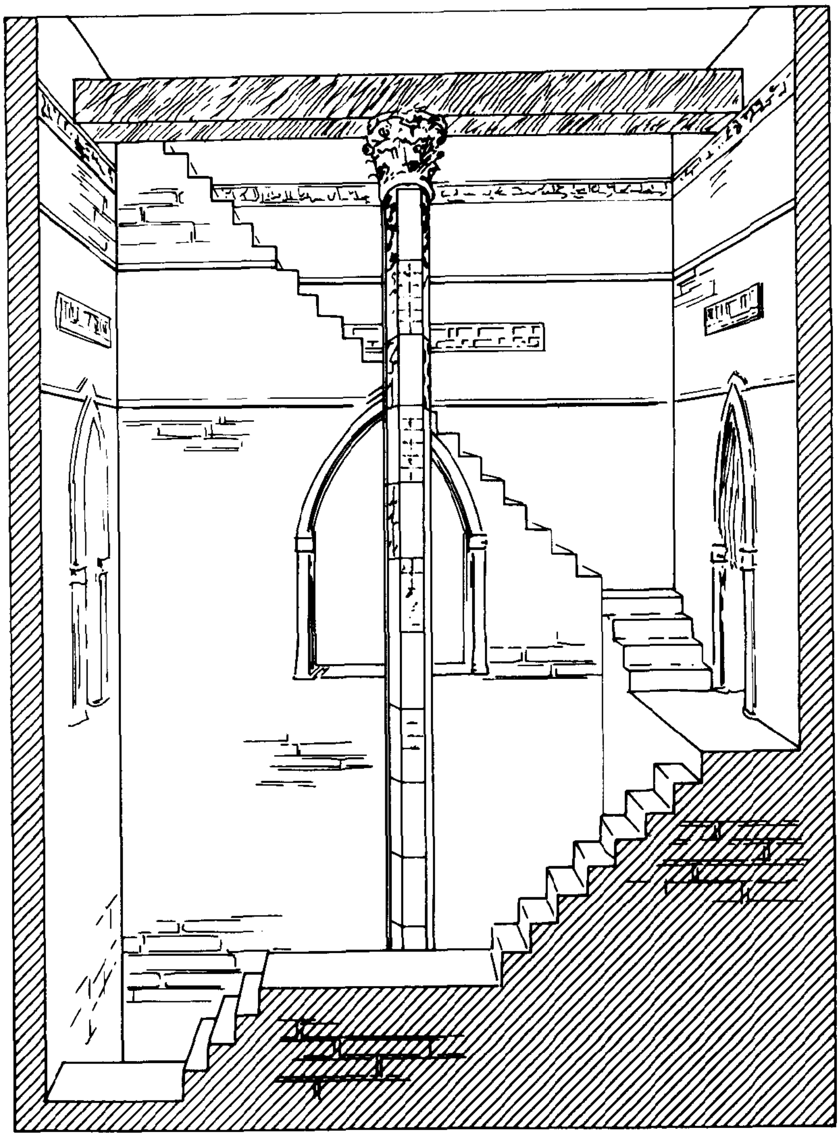

Figure 1-1 The Roda Nilometer in 1798 A.D. (Source: Biswas 1970.)

of knowledge and science were formed. One of their important objectives was to provide a firm scientific foundation for water resources planning and management. Among these groups were England's Royal Society and France's Royal Academy of Science and Corps of Roads and Bridges. From the last-named institution came such pioneer water-resources hydrologists as Chezy.

During the 18th century, many quantitative advances, such as Pitot's formula for measuring the force of fluids, were made. Of the advances, probably the most important was Daniel Bernoulli's energy equation,

$$\frac{v^2}{2g} + \frac{p}{w} + z = \text{constant} \qquad (1\text{-}1)$$

which is basically the principle of conservation of energy. Somewhat later, Euler (Bernoulli's contemporary), added the component of energy as an important variable. The equation is a very useful integral form of Euler's equation of motion.

In the United States, as in some other countries, many advances have been made in the mathematical understanding of hydrology and water resources management. Examples of good planning abound, beginning in the mid-18th century. George Washington, who as a young man worked as a surveyor, was later named the chairman of a group charged with making the Potomac River navigible. To this end, a series of five locks was installed to allow passage of barges past the Great Falls, near present-day Washington, D.C.[2]

The Gallatin report, ensuing from the Lewis and Clark expeditions, represented the first comprehensive water resources plan devised in the United States (1807). Other water resources plans centered on canals as transportation channels, such as South Carolina's Santee Canal (1800) and New York's Erie Canal, which was quickly rendered obsolete by rail transportation.

Under the Desert Land Act of 1877, land grants were made to individuals who agreed to develop the water potential of that land, usually by means of irrigation. From that act came the long-running contests among claimants for water in that part of the United States west of 100° longitude.

John Wesley Powell, the famous pioneer explorer of the Grand Canyon and the first chief of the U.S. Geological Survey, advocated joint land use and water planning. His influence led to the collection of combined topographic and hydrologic data for maps. But Powell's ambitions for the systemic use of that data were often brushed aside in the drive for development in the late 19th and early 20th centuries.

Because of the importance of rivers as both transportation channels and sources of water, many U.S. cities were built on floodplains, with predictable consequences. These hazards have led only recently to joint planning for land use and flood control. Probably the most visible example of this attention to both elements involves the lower Mississippi River. A series of catastrophic floods there eventually proved that only through a combination of detention reservoirs, temporary bypasses, and levees could flooding be controlled.

Another good example of combined land use and flood control planning was Dr. Arthur E. Morgan's study of the Great Miami River basin, in southern Ohio. The study was prompted by an unprecedented flood that ravished the business district of Dayton in 1913. Morgan's plan suggested 63 km (48 mi) of levees and channel improvements through nine major cities and five dry, single-purpose detention reservoirs. The project, completed in 1922, was paid for entirely by local property owners and public agencies.

In addition to its low cost and rational financing, Morgan's plan was a worthy engineering accomplishment marked by the very careful planning that preceded and accompanied every move. Not only were careful and exhaustive data taken for water resources, but related resources, such as energy sources, were also studied. The 10 volumes of technical reports that ensued from Morgan's project have provided a standard for good planning ever since.

In contrast, numerous examples of failed irrigation projects mark the history of the western United States. Had careful studies been made of all the available resources, without preconceived notions, chances are that many of those projects would not have been undertaken. And that is the reason for water resources planning:

[2] T. M. Shad, "Water Resources Planning—Historical Development," *Water Resources Planning in America, 1776–1976*, ASCE Annual Convention and Exposition, Philadelphia, 27 Sept.–1 Oct. 1976, Preprint 275 Y: 10 (hereafter referred to as WRPA). Also published in the *ASCE Journal of the Water Resources Planning and Management Division* 105 (March 1979).

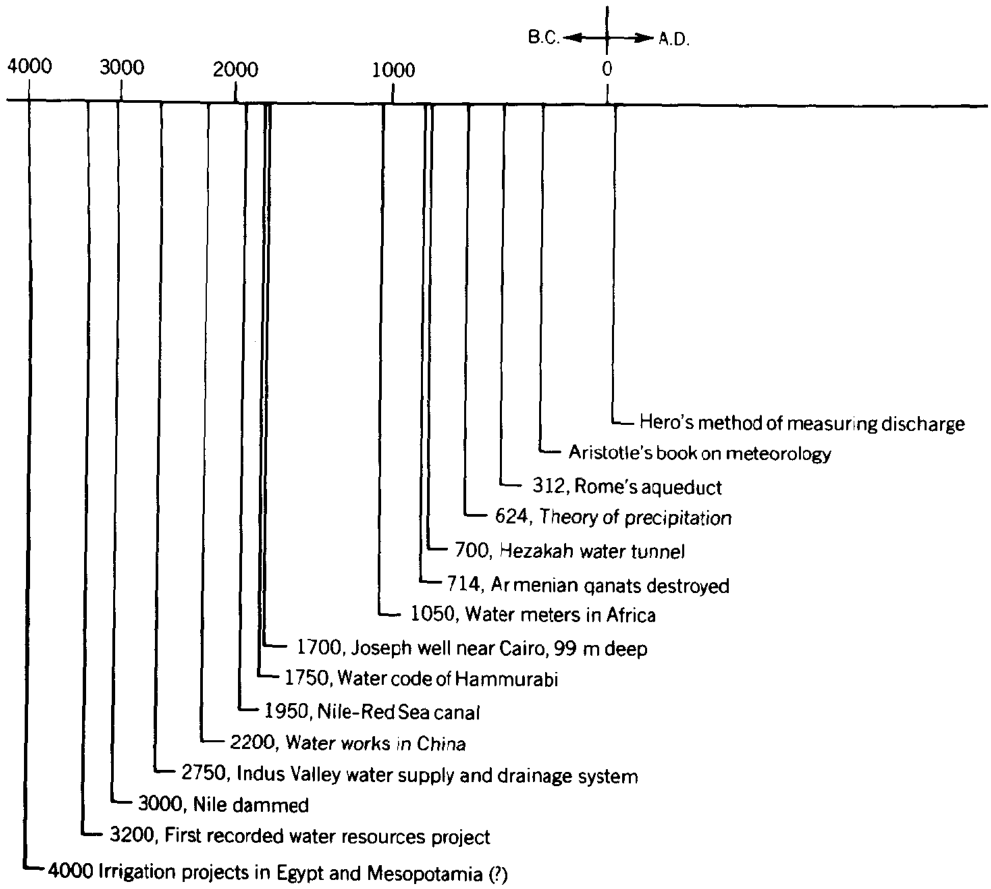

Figure 1-2 Time line of water resources highlights (time on a log scale).

to make optimum use of available water resources so as to achieve the correct balance between conservation and depletion, between use and misuse.

In another area, the first broad-scale planning for communities was carried out by military forces, often in occupied territories. Then came urban planning, as exemplified first, and perhaps best, by the city of Stockholm. After large parts of the city were destroyed by fire, the need for a master plan for rebuilding was recognized. In the rational land use plan that was developed, ample attention was given to zoning, green space, and utilities. The impetus given by that good start has been maintained to the present day, and as a result Stockholm is possibly the best planned city in the world.

More recently, economic planning has been added to the broader concept of planning. Along with recently developed optimization techniques of analysis, such as simulation modeling, statistics, and linear programming, have come tools that the engineer can use to advantage when called upon to present a comprehensive plan.

1-2 PLANNING MODEL

Although much planning literature is written in its own, unique language, we can draw from it a

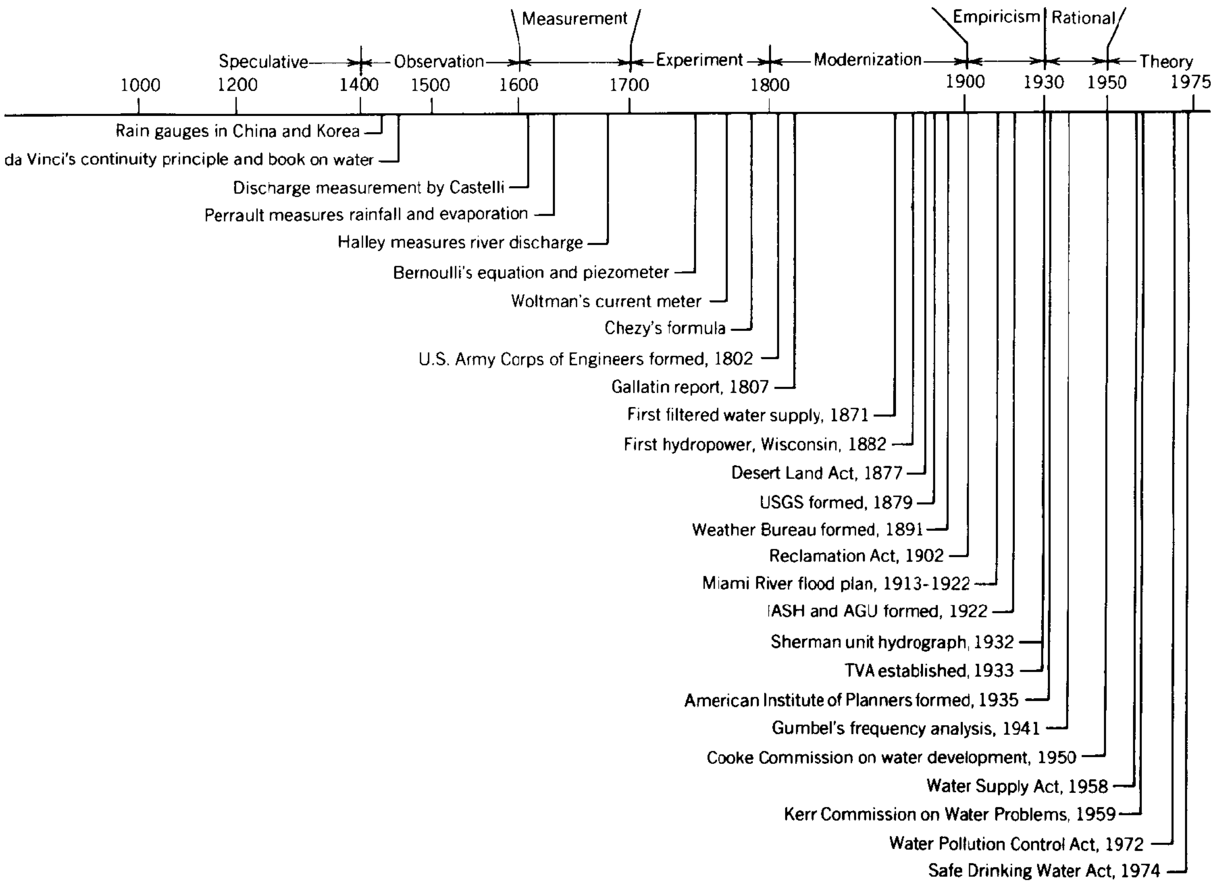

Figure 1-2 (*continued*)

comprehensible set of insights and strategies that will be of use in water resources planning. Of particular usefulness are the steps in the planning process that comprise a planning model. Table 1-1 illustrates the type of planning model that will be followed in this book. Although, as experienced planners know, messy complications can perturb any model, the list given in Table 1-1 provides a good starting point.

The plan of study is extremely important. In it the beginning assumptions should be outlined and clearly defined. What planning approach should be taken? What steps might be needed to complete the plan? How should the time and financial budgets be allocated among the steps? The plan of study lends itself to PERT (planning evaluation and review technique) and other methodologies that are covered in Section 2-3.

Data management, the collection, cataloging, evaluation, processing, and analysis of information, is important for economic as well as technical reasons. Although easily the least glamorous of the planning steps, data management usually provides the key to a good planning study.

In formulating and evaluating alternatives, we will find the tools of systems analysis to be particularly helpful. The optimization of alternatives is possible through several mathematical

Table 1-1
PLANNING MODEL (STEPS IN THE PLANNING PROCESS)

Formulate goals and objectives	Clearly define what the planning study is to accomplish (See Section 2-1.)
Complete Plan of Study (POS)	Set up planning schedule and allocate resources to carry out the plan (planning to plan). (See Sections 2-2, 2-3, 2-4, and 2-8.)
Collect and analyze data	This is really data management, which involves the collection, cataloging, evaluation, processing and analysis of data. (See Chapters 3, 4, 5, and 6.)
Formulate alternatives	Construct the various alternatives that are candidates for the plan. (See Chapter 7.)
Evaluate alternatives	Measure the effects of each alternative and compare them to the objectives, keeping in mind feasibility and probability of implementation. (See Chapter 8.)
Select plan	Select the best alternative from the evaluation process, on the basis of implementability (feasibility).
Implement plan	Carry out the plan. (See Chapter 9.)
Conduct postanalysis	Analyze the results of the plan after it has been implemented, to see how it worked. (See Chapter 10.)

techniques borrowed from the discipline of systems analysis (SA). Simulation models rely on computers and numerical methods. Other tools taken from SA include queuing theory, decision theory, game and control theory, PERT, and CPM simulations. As the phrase implies, in systems analysis one attempts to define and study a system as a whole, in order to design and control it.

1-3 LIMITATIONS OF PLANNING

In the United States, water resources planning, like all central planning, has not been universally accepted.[3] Some individual or group, it seems, invariably feels ignored or slighted. This feeling may reflect a general distrust of a strong central government, or a perceived threat to property rights posed by broad master plans. Disillusionment with comprehensive water resource plans has been compounded when plans have been left to gather dust on a shelf. Also, some plans are formulated simply to use up available funds, or for image-building purposes.

Planning in general has been of great interest, however, to governments of developing countries, despite the volumes of unimplemented plans that may line the bookshelves of their administrators. And although there may be local disenchantment with water resources planning, as with planning in general, many mem-

[3]See National Water Commission, *New Directions in U.S. Water Policy: Summary, Conclusions, and Recommendations from the Final Report of the National Water Commission* (Washington, D.C.: U.S. Government Printing Office, 1973).

bers of the informed community, of the political sector, of government agencies, and of the general public are vocal believers in planning.

1-4 RECENT TRENDS

Some of the above-mentioned disappointment with planning can be overcome if attention is called to recent changes—many of them improvements—in the discipline.

One such improvement has been a greater emphasis on the dynamic nature of plans and planning. Today's final plans, in contrast to the rigidly interpreted plans of the past, are viewed as dynamic, flexible guides. Society changes, and so does its overall guide. A plan that does not reflect those changes may well be more of a hindrance than a help.

Another improvement, as far as engineering planners are concerned, has been the increased emphasis on the client, who is now often given primary responsibility for selecting the plan and for making all the important decisions. The planner should come prepared with a range of opinions and practicable alternatives, but the client must be responsible for the final decisions.

Still another change has been a heightened realization that nonstructural solutions often can serve the planning purpose well. Engineers are trained to build, so it is understandable that their solutions usually contain some kind of structure or change in the physical environment. Now, however, the term *nonstructural* is frequently heard in planning circles. Clients are asking for solutions that include zoning, insurance, and flood-proofing of buildings as well as levees and detention reservoirs. Planners are now looking at natural biological purification processes, such as salt marshes for brackish water. One exemplary water resource project, in Santee, Cal., involves the reclaiming of wastewater and its reuse for recreation, artificial recharge of aquifers, and freshwater barriers against saltwater intrusion.

One recent improvement that carries a broad range of implications has been the consideration of alternative futures for the project being planned. Planners now take into account the real possibility that for a variety of reasons, forecasts of water availability may be wrong, as may forecasts of water requirements for a given activity. Instead of taking a deterministic view, planners now see that it is important to analyze a range of alternative futures.

The painting of alternative futures usually involves the formulation of a variety of scenarios, ranging from "worst case" to "best case." Together with the client, the planner should decide which scenario is the desirable one for the client's objective and devote the plan to that scenario.

Technology assessment is a related strategy. Here the planner asks how the implementation of a new technology, as part of a plan, will affect the social and economic system.

Public involvement has come to play a significant part in the planning process. It is crucial to the elimination of credibility gaps between the planners and those affected by the plan, especially in such broad-scale plans as those for water resources projects. The Corps of Engineers' "fish bowl" approach, in which as many people as possible are kept informed about the planning deliberations, and other such approaches have made public involvement a standard feature of the planning process. Although a true cross section of the public rarely appears at open meetings related to water resources planning, those persons who are sufficiently interested should be able to interact with the planners. From that interaction may well come valuable additional information. Great strides need to be made to refine communication between the decision makers and the "publics" (a term used here to emphasize the variety of groups that together constitute the general public).

Another refinement generally thought of as an improvement has been the emphasis on environmental concerns. The realization that earth's resources are finite and can be spoiled or wasted by human activities has made planners recognize that environmental protection must be paired with economic objectives. The traditional cost-benefit analysis assumed a perfect market that did not exist, for water or any other natural resource, and economic efficiency does not necessarily produce a good environment. Many planners now look at projects with an eye toward producing a better overall plan, even if that means a decrease in the net benefits in dollar terms.

Multiobjective analysis also represents a new, improved view of planning. Simply stated, multiobjective analysis allows nonmonetary values to be compared with monetary goals. Finally, the techniques of computer simulation have become commonplace in water resources planning.

In summary, water resources planning in the near future may well emphasize conservation and environmental concerns, especially in the developed countries. Better water management will be seen and stressed for existing systems. The future of large reservoirs probably will remain in doubt, however. Hydropower represents an attractive investment, as do surface reservoirs for regulating stream flows, but environmental effects and rising costs may outweigh the apparent benefits. Increased emphasis on aquifers as storage reservoirs and the control of groundwater quality may also receive increased attention. An increasing use of data banks with water resources data also seems certain. With the undeniable trend toward more planning, and with the better tools available, the future of water resources planning and management will be even more challenging and exciting in the future.

Having reviewed some changes in planning philosophies and practices, we may now ask the very basic question, Is planning desirable? Abraham Lincoln answered that question succinctly:

If we could first know where we are and whither we are tending, we could then better judge what to do and how to do it.[4]

Rational planning uncovers the best ways to attain desired ends, contributes to learning, and helps us to control the growth process. This is certainly preferable to drifting. Even where planning does not yield a decision, because of shifting variables, the process increases our knowledge as planners.

The purpose of planning, in one sense, is to anticipate problems. Similarly, planners may discover and capitalize on opportunities if there is sufficient latitude in the process. Planning serves a vital purpose, and deserves acceptance, if it

1. Achieves broad objectives related to the real goals and needs of people rather than merely to the development of resources.
2. Is based on meeting the goals and needs of a spectrum of people rather than of just one interest group or elite.
3. Illuminates alternatives through which decision makers can achieve these goals instead of rigid structures through which planners impose their will on the public.
4. Asks only for necessary, immediate decisions rather than foreclosing future options unnecessarily.
5. Is conducted in an institutional framework that allows implementation instead of being set forth as a report that winds up on someone's shelf.
6. Is done only when necessary rather than because funds are available or to enhance an image.
7. Adequately involves the public in all decisions.

[4]From H. H. Humphrey, *A Proposal for Achieving Balanced National Growth and Development* (Washington, D.C.: U.S. Government Printing Office, stock no. 5270–01715, 26 Feb., 1973.)