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Introduction

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SYMPOSIUM: WATER RESOURCES RESEARCH

INTRODUCTION

In the last decade water has become an increasingly popular topic. In the last half of the decade considerable attention has been focused on and devoted to research on water resources. With the passage of the Water Resources Research Act in 1964, and with the current review by Congress of the overall research program of the federal government, this appears to be an appropriate time to assess research needs in the field of water resources.

As Hufschmidt indicates in his paper in this symposium, there are various ways of classifying research problems in the water resources field. He suggests several. Tolley also suggests a system for classifying research efforts. Eschewing any attempt to differentiate between "basic" and "applied" research, the water resources field in relation to research can be classified broadly into three major areas. These are: (1) research oriented toward understanding the physical nature of water resources, *i.e.*, the entire hydrologic cycle; (2) research on engineering problems in the development and utilization of water resources, and (3) research relating to the planning and operation of water resources systems.

Examples of research problems with respect to the hydrologic cycle include: (1) the mechanics of overland flow; (2) the nature of, and factors influencing, variations in annual runoff; (3) the relationships between stream channel shape and discharge, sediment load, and size of bed material; (4) the effects of vegetation and forest management on streamflow and sedimentation, and (5) diffusion phenomena in tidal estuaries. Such research is primarily in the area of the earth sciences—hydrology, meteorology, oceanography, geomorphology, plus hydraulics and fluid mechanics.

The second general area, engineering problems, techniques, and costs relating to water resources development and utilization, includes: (1) techniques and facilities for recharging ground water basins; (2) advanced techniques for treatment of wastes; (3) techniques for reclaiming waste water; (4) the design of fishways; (5) problems of recirculating water within various types of industrial plants; (6) methods for re-aerating streams and reservoirs; (7) methods for desalination of sea and brackish water, and (8) the design and development of instruments for measuring the quantity and various water quality parameters of streamflow, in-

cluding automatic monitoring. This general area of research involves engineering design, construction, and testing of facilities for utilizing or developing water resources, in contrast to the first area, which involves research to advance the basic understanding of the physical nature, and interrelationships among the components, of the hydrologic cycle.

The third general area encompasses such problems as: (1) the process of water resources planning; (2) methods for computing benefits associated with outputs from water resources systems; (3) procedures for the optimal operation of integrated systems of surface and ground water reservoirs and of structural and non-structural measures; (4) methods and institutional arrangements for integrating public and private decisions with respect to water resources development and utilization, *i.e.*, flood plain user and regional water agency, local water company and regional water agency; (5) procedures for decision-making under various constraints, policy alternatives, and multiple goals; (6) methods for handling the different types of uncertainty involved in water resources planning and development; (7) administrative mechanisms for continuous planning and operation of water resources systems, and (8) needed modifications in water law to enable optimal utilization of water resources. The preceding area of water resources research is divided somewhat arbitrarily into two aspects. This has been done solely to provide emphasis by distinguishing between the planning aspects and the operation or management aspects.

However classified, the research outputs from the various segments of the water resources field can be thought of as coming together in the actual day-to-day planning, development, and management of water resources. Information on the physical nature of water resources, on the engineering facilities and methods available for development and utilization and their costs, and on various techniques for making decisions with respect to investments in water resources development and with respect to system operation after construction—all are integral components of efficient water resources administration. Ultimately, all these research activities contribute to the primary goal of efficient allocation of resources in society. It should also be emphasized that water resources planning is merely one facet of the overall problem of regional planning and development.

To illustrate how the various categories of research are tied together in relation to one particular problem, consider ground water

recharge. There are still gaps in our understanding of ground water flow, particularly with respect to the physical and chemical reactions between the aquifer and water of different qualities. Engineering methods for recharging aquifers over long time periods and the costs thereof are still in need of development. In the planning phase, the specific methods by which a water resources planner in an agency incorporates ground water recharge in alternative water resources systems, including surface reservoir storage, various water and waste treatment facilities, and various outputs from the system, require further research for day-to-day application. Even if knowledge were adequate with respect to ground water movement, engineering facilities for recharge, and the manner in which the planner can incorporate the consideration of ground water recharge in operational studies of alternative water resources systems, there remain legal and institutional (administrative) problems in relation to actual utilization of recharge techniques.

Efforts have been made to list areas of needed research in water resources by various agencies, such as the American Society of Civil Engineers, the American Geophysical Union, and the Federal Council for Science and Technology.[1] These efforts have focused primarily on the physical nature and the engineering aspects of water resources. Related economic and social problems have occasionally been mentioned. To illustrate, Tinney[2] cited the following classification of the seventy-six million dollars to be spent for water resources research by the federal government in 1964:

(1) Evaluation, prediction, and modification of the water cycle, 22%;

1. See, *e.g.*, American Soc'y of Civil Engineers, Program for National Symposium on Sanitary Engineering Research, Developments and Design (Pa. State Univ. 1965); American Soc'y of Civil Engineers, *1964 Irrigation and Drainage Research Conference*, 90 ASCE (1964); Linsley (chairman), *Meeting of AGU Committee on Status and Needs in Hydrology*, 45 Am. Geophysical Union Trans. 693-98 (1964); McGuinness, Groundwater Research of the U.S. Geological Survey (U.S. Geological Survey Circular No. 492, 1964); U.S. Federal Council for Science and Technology, Ad Hoc Panel on Hydrology (1962); American Soc'y of Civil Engineers, Symposium on Basic Research in Civil Engineering Fields Related to Water Resources (Colo. State Univ. 1961); National Reclamation Ass'n and National Ass'n of Soil Conservation Districts, *Proceedings of the National Water Research Symposium*, S. Doc. No. 35, 87th Cong., 1st Sess. (1961); McGauhey, *Ground Water Contamination Research and Research Needs*, in Proceedings of Ground Water Contamination Symposium 181 (Tech. Report No. W61-5, Taft Sanitary Eng. Center 1961), and McKee, *Research Needs in Ground Water Pollution, id.* at 205.

2. Tinney, Panel Discussion in Water Resources Management for the Needs of an Expanding Economy (Seminar, Univ. of Wash. 1964) (mimeo.).

(2) Qualitative aspects, 20%;
(3) Water re-use and separation, 15%;
(4) Water in relation to land management, 14%;
(5) Water resources development and control, 8%;
(6) Engineering, 8%;
(7) Basic research on the nature of water, 6%;
(8) Economic and institutional aspects, 4%; and
(9) Uncategorized grants by the National Science Foundation, 3%.

The most recent tabulation of research in the water resources field is that by the new Office of Water Resources Research in the Department of the Interior.[3] This latest tabulation and the various other tabulations cited raise the logical question of whether or not priorities should be established among the various areas of needed research relating to water resources. On what basis or bases might such priorities be established? Who should be responsible for establishing the priorities?

The problem is one of determining the optimal pattern of "investment" in research itself. This is no easy task, and in fact may be impossible, because of the inability to evolve criteria by which research efforts—or the potential usefulness of research efforts, in the three areas can be evaluated and compared. Priorities are also difficult to formulate because of the wide dispersal of research activities among many agencies, institutions, and individuals, resulting in less than complete knowledge of existing research efforts.

In spite of these difficulties, the Office of Water Resources Research might well attempt to provide leadership in assessing the extent of knowledge in the various areas of the water resources field and indicating the major gaps. The alternative is for the Office and other funding agencies, such as the National Science Foundation, merely to pass on individual proposals, without any attempt to establish an overall framework relating to water resources research and research needs. This alternative procedure of evaluating individual proposals has been the practice of the Public Health Service in relation to its research grants, except for its Advanced Waste Treatment Research Program (AWTR).[4] With respect to

3. U.S. Office of Water Resources Research, Federally Supported Research in Progress, Water Resources Research Catalogue, vol. 1 (Dep't of the Interior, June 1965).

4. U.S. Public Health Service, [Jan. 1962-June 1964] Advanced Waste Treatment Research Summary Report, Division of Water Supply and Pollution Control (AWTR-14, Dep't of Health, Education and Welfare).

the AWTR program, the Public Health Service first formulated the overall program; second, defined the areas of needed research; and third, proceeded to carry on the research through both intramural and extramural means. The important point is that all segments of the research were designed to fit within a defined framework. This is not meant to suggest that there is no place for the individual proposal, but rather that higher efficiency in terms of results can be achieved by at least some measure of preliminary formulation of research needs.

The articles to follow are essentially limited to the discussion of research needs in relation to the third area, water resources planning and operation. Hufschmidt emphasizes problems with respect to water resources planning. Kneese, Tolley, and Bower range over aspects of both system planning and system operation.

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