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Economic and Related Problems in Contemporary Water Resources Management

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[SYMPOSIUM]

ECONOMIC AND RELATED PROBLEMS IN CONTEMPORARY WATER RESOURCES MANAGEMENT

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One can easily think of good reasons why this is an appropriate time to assess current directions of economic and other social sciences research, and research needs, in water resources.

Congress has recently enacted the Water Resources Research Act[1] authorizing establishment of water resource research centers in each of the fifty states. Many of these centers should, and will want to, direct a large part of their efforts toward economic and social sciences problems.

Furthermore, the federal water resource agencies in cooperation with state and local agencies are engaged in a truly massive planning effort. By the end of the decade "framework" or Type I water resources plans are to be finished for all the major basins of the United States. By this time also a number of specific or Type II plans are to be finished and others will be well under way. In addition to the federal effort, there are many state and interstate undertakings, including that of the new Delaware River Basin Commission with its far reaching concepts of comprehensive planning and regional action. Water resource plans and action programs will be largely directed toward the achievement of economic objectives. In many instances, however, economic planning methodology and the ability to generate, analyze, and project relevant economic variables are in a primitive state. In considerable measure the new planning and action efforts reflect the changing character of the challenges which confront us in the development and use of water resources.

New problems and opportunities have arisen from (1) the continued rapid urbanization and industrialization of American society; (2) the growth of population conjoined with an enormous expansion of the economy, and (3) the unprecedented rapidity of scientific and technological change.

As a consequence of these factors, we find ourselves less often con-

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1. 78 Stat. 329-33, 42 U.S.C. §§ 1961 to 1961-c-6 (1964).

fronted with the problem of developing unused water supplies to promote economic expansion in certain areas and more often confronted with problems occurring where strong conflicts between uses have already developed. Instead of harnessing unused potential for irrigation and power, we face the increasing problem of managing resources in regions where demand for services from water courses is already heavy. Although problems differ in detail, the generalization holds for the more highly developed basins in both the East and the West. Moreover, many of the services experiencing strong and rapidly growing demand have received comparatively little analysis, especially in evaluation of benefits and costs. Major examples of these services are waste disposal, municipal water supply, and recreation.

In many of our river basins, especially the more highly developed ones, flood control continues to rank as an important water management activity. Indeed, it is still (but probably will not continue to be) the major economic justification for Corps of Engineers projects. And massive navigation projects are still pending in some areas.

This complex of intensive and frequently conflicting demands for water services presents new and difficult problems. We now confront a far different situation than when water supply problems were largely local, waste assimilative capacities of streams were ample to handle effluents discharged into them, and reservoirs were primarily useful for power generation, to supply irrigation water, and to provide flood protection for specific localities.

The water resource economist-planner now frequently faces a truly imposing array of problems—evaluating water services whose market purchase at best generates only indirect indications of the relative value people place on them; tracing and evaluating complex interdependencies or systems effects, often over large geographic areas; and helping to guide decisions involving great uncertainty due to the rapid pace of economic and technological development. These problems also raise the serious question whether existing institutional and legal arrangements are appropriate for the intricate problems we confront.

To further complicate the matter we now see water resources projects seriously proposed as instruments for counteracting the decline of one of our oldest settled regions. Under the Appalachian Regional Development Act[2] the United States Corps of Engineers

2. Pub. L. No. 89-4, 89th Cong., 1st Sess. § 206 (March 9, 1965), U.S. Code Cong. & Ad. News, March 20, 1965, pp. 102-03 (79 Stat. 5).

is instructed to devise a comprehensive water resources plan that will not be limited merely to identifying projects which could efficiently meet present and projected future demands for water, but a plan that will serve as an instrument for stimulating and promoting growth.

If the objective of developing Appalachia or any other depressed region is accepted as an appropriate policy objective, several important and difficult problems confront water resource economics: (1) What are the direct local impacts of water resource investment and what is the propensity of subsidized water to attract income generating activities to a region? (2) How important a factor in the location of water-using activities are the cost and quality of water? (3) Is investment in water resources the most efficient way to achieve development? (4) What methodologies and criteria are appropriate to assure achievement of regional development objectives with a minimum sacrifice of overall national economic development?

I

CONTRIBUTIONS OF ECONOMIC THEORY

By stressing problems and unanswered questions I do not mean at all to imply that economics and economic research have not made a significant contribution to the efficiency of water resources development and use. Economic theory has provided an operational normative model for water resources planners. This conceptual model of efficient resources allocation is the fundamental basis for many basic official documents setting out standards and procedures for water programs. It is fair to claim that the Green Book,[3] studies by the President's Water Resources Council,[4] and the Delaware River Basin Compact[5] fit this description. Through use of this model it has been possible to be rather specific about decision criteria in the planning of projects and systems. Furthermore, it has been possible to formulate workable empirical approaches to estimation of the benefits and costs that the model instructs us to compare.

3. Sub-Comm. on Evaluation Standards, Proposed Practices for Economic Analysis of River Basin Projects: A Report to the Inter-Agency Committee on Water Resources (rev. 1958).

4. The President's Water Resources Council, *Policies, Standards and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Land Resources*, S. Doc. No. 97, 87th Cong., 2d Sess. (1962).

5. Delaware River Basin Advisory Comm. for the Use of the Delaware Basin Comm'n, Delaware River Basin Compact (1961).

Although the analytical and measurement problems we cannot yet deal with, or can deal with only inadequately, are difficult and demanding of ingenuity and persistent effort, I feel that there is reason to be optimistic that improved approaches can be devised. Indeed, in some cases considerable progress is already apparent.

In the following sections I will describe some of these major current challenges in somewhat more detail. As examples of the type of research directed toward these challenges, I will cite projects sponsored by Resources for the Future. This does not imply that no other worthwhile work is being done in this area, but is only to illustrate concrete efforts presently under way to cope with these challenges. I will also point to problem areas where it seems to me additional research is urgently needed.

II

WATER TRANSFER PROBLEMS

A particularly important economic-legal institutional problem resulting from heavy and competitive development of water resources is well illustrated by several major basins in the West. Economic projections have indicated that in these basins continuation of present water use patterns over the next several decades would lead to *over-exhaustion* of available supplies even under the fullest possible regulation of flow. These projections might easily lead to a conclusion that the economic development of these regions must come to a grinding halt within a comparatively few years. This result is, of course, not certain for several reasons. For example, it may be possible to divert water into these areas via large-scale diversion schemes; I will have a few more words to say about this later.

Additionally, research done by Nathaniel Wollman and others from New Mexico demonstrated several years ago that reallocation of water from agricultural to industrial, municipal, and recreational uses is capable of greatly expanding the development potential of water-short regions.[6] This possibility emphasizes the great importance that efficient mechanisms for the transfer of water from lower to higher value uses may have in these areas. Not only is it important that water be smoothly transferred to support industrial and urban growth in these areas if they are to continue to grow, but as water supplies become more stringent it also becomes highly signifi-

6. N. Wollman, The Value of Water in Alternative Uses (Univ. of N. M.1962).

cant that water used in agriculture is applied to the most productive lands and crops by the most efficient managers. The critical importance of the economic, institutional, and legal mechanisms by which water allocations and reallocations take place is thus evident. Although many observers feel that these mechanisms function inefficiently, we are only now beginning to understand in adequate detail their operation and some of the problems such transfers involve.

Some of the most difficult problems in understanding and helping to shape better mechanisms for achieving efficient allocation of water arise from the economic effects on third parties (non-participants in the market-determined decision to transfer) when transfers, especially large-scale ones, occur. These third parties include the service community to an irrigation project, downstream users dependent upon return flows, and downstream users affected by changes in the quality of flow attendant to changes in use. This gives rise to the extremely important question of how effectively the market exchange of property rights in water (the mechanism implied by the prior appropriation doctrine of the western United States) can lead toward economically optimal water allocation in view of such effects.

One study of this problem is under way by a team of researchers (economists, lawyers, and hydrologists) at Colorado State University in Fort Collins. Resources for the Future is sponsoring this study, which is really a continuation of a line of RFF research begun several years ago that resulted in publication of Wollman's *Value of Water in Alternative Uses*.[7]

Progress is being made toward a substantial conceptual and research basis for devising more efficient modes of water transfer in the arid west. It is not yet clear that the best means will be the exchange of water rights in markets because of the difficulty in arriving at reasonably certain definitions of rights when major third party effects, resulting from water quality deterioration and return flow dependency are involved. Perhaps the most satisfactory solution will be some mixture of market transfers of rights and administrative allocations.

A partial or complete alternative to massive water reallocation is the augmentation of regional supplies by one means or another. These include desalinization of brackish water, sea water conversion, watershed management, various means of reducing evapotranpiration, inducing rainfall, and long distance diversion from

7. *Ibid.*

areas more richly endowed. These measures are all amendable to benefit-cost analysis and, in fact, applications have been made to them to some extent. Of the possibilities listed, the one promising to have far and away the greatest application in the foreseeable future is long-distance diversion. The California Water Plan and the Central Arizona, the San Juan-Chama, and the Frying Pan-Arkansas projects are all examples of large-scale diversions in the advanced planning or early execution phase. A massive long-distance diversion that has been under discussion for some years is from the East Texas Basins along the Gulf Coast Plain to South Texas. An even more imposing scheme has recently been proposed by the Ralph M. Parsons Company. This engineering firm suggests a $100 billion development to divert water from Alaska and Western Canada across the Continental Divide into the Colorado, Missouri, Arkansas, and Gulf river basins, as well as California's Central Valley.[8] Without suggesting that large-scale diversions are never economically justifiable (it is obviously possible to imagine situations in which they are), it must be said that there is little or no indication that such projects have ever been evaluated in view of the full range of possible alternatives, including water reallocation from existing low-productivity uses, systematic water renovation and reuse, and water pricing that adequately reflects the costs of supplying the water and the value of alternative uses forgone. A case study in depth of at least one of these proposed diversion projects could be very useful in developing methodologies and insights for the planning of additional projects of this kind.

III

RECREATION BENEFIT ESTIMATION

Next let me turn to a problem of general relevance throughout the United States. One of the most important research problems in the entire field is to improve our ability to estimate the benefits that accrue from water-based recreation. Use of outdoor recreation facilities is increasing much faster than population and even faster than per capita income. The role of recreation demand in water resources development and use is also expanding rapidly. Long and inaccurately known as an "intangible," recreation benefits are now being attributed to reservoir projects in monetary terms by the

8. See Business Week, Sept. 26, 1964, p. 134.

federal agencies. A document entitled *Policies, Standards and Procedures in the Formulation, Evaluation, and Review of Plans for the Use and Development of Water and Related Land Resources*, prepared under the direction of the President's Water Resources Council, gave authoritative sanction to this practice.[9] Some strikingly large recreation benefits have been attributed to reservoirs in both the eastern and western regions of the United States. Illustrative are the Auburn Reservoir of the Bureau of Reclamation on the American River in California, where over $40 million of costs have been allocated to recreation; the proposed Potomac River projects of the Corps of Engineers, where $140 million have been allocated to this purpose, and the Tocks Island Reservoir, proposed as a national recreation area in the Delaware Basin.

Moreover, producing or maintaining high quality water in many areas can be justified, if justified at all, only on the basis of the recreation benefits it yields. If we are to introduce a rational weighing of costs and benefits in the huge water quality management programs that are in prospect, it will be necessary to discover ways of establishing a functional relationship between the value of recreation and water quality.

It appears that present planning procedures will result in new federal reservoirs being justified in large measure on the basis of recreation directly on and near the reservoir and, particularly in the East, for flow regulation benefits attributed to downstream water quality improvement that is ultimately in the interest of recreation.[10] The standard figure per visitor day now used by the federal agencies to assign benefits to recreation is arbitrary, and no attempt whatever has been made to assign benefits directly to downstream water quality improvement. In fact, water quality improvement benefits as presently calculated are based upon alternative costs of achieving the same objective and are not systematically related to willingness to pay for improved water quality.

I am in no way attempting to dispute the legitimacy or the importance of recreation benefits, but I am asserting that present modes of calculating them amount to little more than multiplication of two arbitrary numbers. Furthermore, if recreation benefits are indeed

9. See President's Water Resources Council, *supra* note 4.

10. As an illustration of the role that low flow augmentation is playing in the long-range planning of the U.S. Corps of Engineers, see E. Weber, *Relation of Regulation for Quality to Activities of the Corps of Engineers*, in Symposium on Stream Flow Regulation for Water Quality Control (Taft Sanitary Engineering Center 1963) (mimeo.).

important, they should be a factor in the design and scale of the elements entering into the water resources system and in the mode of operation of the system. For example, recreation benefits are certainly a function of the proximity of reservoirs to urban areas and the drawdown of reservoirs. As an extreme example, it might be efficient to locate single-purpose (not drawn down) reservoirs quite close to some urban areas as a partial or complete substitute for developing access to and recreation opportunities around large multiple-purpose reservoirs. We may have become so wedded to the multiple-purpose concept that it is now causing us to overlook single-purpose developments that are on occasion more efficient.

More generally, we do not have the institutional means, or even the analytical methodology, to design regional recreation systems in view of the full range of alternative possibilities. In the absence of means and methodology, one may fear that development of opportunities for outdoor recreation will become unduly tied to the federal multiple-purpose reservoir program; institutional forces also tend in this direction. In inland areas the only legally permissible large-scale federal investment in recreation facilities, other than national parks, is in connection with large federal multiple-purpose reservoirs. To compound this possible distortion, attendance at such reservoirs has been non-reimburseable, at least to the present time. In view of this a recreationist will choose this form of recreation, though he might prefer, if given an even choice, a privately provided alternative that will not become available unless he is willing to and does pay for it.

We must develop means of relating recreation values to a variety of economic and social variables, as well as to the character of the opportunity provided and to the substitutes available. This is necessary to provide systematic and meaningful projections of recreation demand in regard to recreation opportunities becoming available with improved water quality, flow regulation, and the provision of reservoir surfaces with various characteristics.

Promising progress is being made in this direction. For example, a member of the RFF staff has been working with the Tennessee Valley Authority and the Corps of Engineers to devise means for empirical estimation of recreation benefits in at least a limited system context. The procedure used imputes willingness to pay by users for access and then employs a mathematical model to project these benefits to new situations. The technique is promising but still limited in the scope of variables that it can encompass and the degree to which it can incorporate systems effects. Moreover, serious problems remain connected with the imputation of demands from access cost data.[11]

In regard to the relationship between recreation values and water quality, RFF is currently sponsoring a project in the Delaware Basin to estimate the willingness of present and potential users to pay for quality improvement in the estuary area. Bordering the Delaware estuary is one of the most important urban industrial complexes in the country, encompassing the cities of Trenton, Philadelphia, and Wilmington, with their imposing complex of steel, heavy chemicals, food, and other waste-discharging industries. Despite substantial efforts to reduce waste loads through treatment, the Delaware estuary almost annually experiences very low dissolved oxygen conditions that are detrimental to its recreation value. The impact of this condition, which can have rather extreme ecological effects in the estuary on other water uses, appears to be modest. Some preliminary studies of the Public Health Service indicate that it may cost several hundred millions of dollars to raise the dissolved oxygen condition to fifty per cent saturation. The primary beneficiaries of increasing the oxygen level would be the recreational users of the estuary. The objective of the study at the University of Pennsylvania is to develop procedures for evaluating quantitatively the magnitude of these benefits to provide a comparison with costs. In doing this, an effort will be made to adapt the procedure developed by Marion Clawson and Jack Knetsch of RFF and to explore other possible methodologies.

The area of recreation research is so important, so much still needs to be done, and the possibilities of substantially improving major decisions over the next several decades are so large that it should be one of the major foci of economic research in the water resources area.

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11. See the following papers by J. L. Knetsch, *Outdoor Recreation Demands and Benefits*, Land Economics, Nov. 1963; *The Influence of Reservoir Projects on Land Values*, J. Farm Economics, Feb. 1964, p. 231; *Economics of Including Recreation as a Purpose of Water Resources Projects*, to be published in the 1965 *Proceedings* of the American Farm Economics Ass'n. For a general assessment of outdoor recreation research possibilities, see M. Clawson & J. L. Knetsch, Outdoor Recreation Research (Reprint No. 43, Resources for the Future, Inc. 1963). The first systematic effort to impute demand from access cost is found in M. Clawson, Methods of Measuring the Demand for and Value of Outdoor Recreation (Reprint No. 10, Resources for the Future, Inc. 1959). For an alternative methodology, see R. K. Davis, The Value of Outdoor Recreation: An Economic Study of the Maine Woods (unpublished dissertation, Harvard University 1963).

IV

WASTE DISPOSAL PROBLEMS

Widely accepted projections of population and industry clearly point to large further demands upon our water resources to receive, assimilate and transport wastes.[12] Projections indicate that virtually the entire net increase in population between now and the year 2000 will be in metropolitan areas.[13] Research by Nathaniel Wollman, done under the sponsorship of Resources for the Future and initially in conjunction with the Senate Select Committee on National Water Resources, points to water quality as the major national water resource problem in the coming decades, especially in the eastern United States. Wollman's work indicates that many tens of billions of dollars may be spent in the next two or three of decades to maintain comparatively good water. His study, the final version of which will probably be published during the coming year,[14] provides a useful conceptual framework for comprehensive projections of water supply and demand, using flow as a common denominator and waste disposal as one of the uses which demands a flow of water (for dilution purposes).

Wollman's procedures have been extremely valuable in pointing to the general magnitude of the problems we confront. Nevertheless, actual water resource management programs that aim at optimum investment in and use of this resource must rest upon a detailed and specific identification and evaluation of alternatives and a systematic balancing of such alternatives to reach an optimum system. If we focus upon water quality, for example, the various means of quality control must be identified, evaluated and balanced among themselves and against the damages associated with poor water quality. To do this in even a rough way, we must greatly improve our ability to evaluate the benefits and costs of water quality control with regard to almost every water use and alternative means of control. The need for evaluation of effects on recreation has already been indicated, but there are also important economic studies to be done of other aspects of benefits and costs.

12. Senate Select Comm. on National Water Resources, 86th Cong., 2d Sess., Water Resources Activities in the United States: Water Supply and Demand (Comm. Print No. 32, 1960).

13. Senate Select Comm. on National Water Resources, 86th Cong., 2d Sess., Water Resources Activities in the United States: Population Projections and Economic Assumptions 15 (Comm. Print No. 5, 1960).

14. N. Wollman, Water Supply and Demand (publication forthcoming).

The Public Health Service has estimated that about twice as much degradable organic waste material is discharged into water courses by industries as by municipalities.[15] An even higher proportion of other directly discharged waste materials stems from industry. Moreover, industries directly withdraw from water courses and use about five times as much water as do municipalities. Some of this withdrawn water is treated to adjust quality for particular process uses. While it may be an important benefit of water quality improvement, the actual economic advantage accruing to industry because of avoided treatment costs or less damage to industrial processes is a virtual unknown in most cases.

Similarly, while one of the major alternatives for reducing waste loads is the redesign of industrial processes to conserve materials or recover by-products, very little systematic information is available that would help relate various levels of waste reduction by these means to the costs of achieving them. *In sum*, industry data relating qualities and quantities of input water and qualities and quantities of effluents to costs that industry incurs are so limited in number and untrustworthy in nature as to be almost useless, despite the fact that these data are of central importance to the planning and operation of water quality control systems in urban industrial regions.

In view of this, RFF has instituted several industry studies. These studies attempt to devise methodology and empirical information concerning the costs that industry experiences when its water supplies deteriorate and upon identifying and evaluating in a systematic way the technical alternatives for handling the industrial waste problem, including process changes and waste reclamation, as well as treatment. These studies are aimed, on the one hand, at defining loss functions that occur when industrial input water deteriorates and, on the other, at determining the costs associated with reducing waste loads to various degrees by optimal combinations of measures. As already indicated, in a number of the major waste producing industries process adjustments, as well as treatment, are of major importance in this regard. In the pulp and paper industry, for instance, the BOD_5 waste load produced by some plants may be twenty-five times higher than those plants practicising waste mitigating procedures. In the beet sugar industry preliminary results suggest that waste loads per unit of output have dropped radically

15. M. Stein, *Problems and Programs in Water Pollution*, 2 Natural Resources J. 388, 397-98 (1962).

over the last few decades solely as a consequence of process changes.[16]

The industry studies are also systematically exploring the costs of opportunities for reducing intake by means of recirculation processes and for mitigating actual water losses in production processes. The canning, pulp and paper, and beet sugar industries are currently under study in this context. The study of the thermal electric power industry is finished and will soon be published.[17] While we hope that these studies will make an important contribution to the planning and operation of water resource systems, opportunities for productive study in this area will by no means have been exhausted. Chemicals and petroleum refining, for example, are of great importance and present unusually difficult challenges to research.

Another facet of the industrial water economics problem is brought into sharp relief by the emphasis placed on the alleged promotional impact of copious supplies of clean water to attract industry to Appalachia and other chronically depressed areas. The studies under way, and those already completed, should help shed light upon water as a factor in industrial location. Before we commit ourselves to a large program of water resource investment based on the presumption that developed water resources are a large attractant to industry, it would seem wise to systematically investigate exactly how important this factor is. Opportunities for water conservation and for the effective handling of wastes are so extensive in some industries that one might hypothesize that the availability of water, beyond some minimal amount, has a very low order of impact on industrial location decisions in these cases.

V

CASE STUDIES

The economics of some other measures for the integrated management of water quality and quantity can be studied to good effect in the context of actual cases. For example, this approach would

16. For a study in the differences in waste loads resulting from process differences in a variety of industries see W. Bucksteeg, Problematik der Bewertung giftiger Inhaltsstoffe im Abwasser und Moeglichkeiten zur Schaffung gesicherter Bewertungsgrundlagen (Problems in the Evaluation of Toxic Materials in Effluents and Possibilities for Obtaining Secure Evaluation Standards), Muenchner Beitraege zur Abwasser-Fischerei-, und Flussbiologie, Band 6 (Muenchen: Verlag R. Oldenbourg 1959).

17. P. H. Cootner & G. O. G. Lof, A Model for the Estimation of Water Demand for Stream Electric Generation (Resources for the Future, Inc., publication forthcoming).

appear to be rewarding in assessing the role of measures such as stream flow regulation; temporary lagooning and scheduled discharge of wastes; instream stabilization ponds, and various other measures to enhance the self-purification of streams; and in regional systems aimed at efficient quality management as an integral part of water resources development and use. For any given level of water quality to be achieved, efficiency requires that the incremental costs of all these various alternatives be brought into equality. The comparative costs of the measures listed depend to an unusual degree upon hydrological circumstances, land values, the availability of reservoir sites and, in the case of flow regulation, the value of other competitive or complementary water uses.

Resources for the Future has under way two case studies of areas displaying a variety of conditions of hydrology, population, industrial distribution, climate and multipurpose development.[18] We feel that these studies will contribute valuable methodology and information for the planning and operation of water resource systems, especially in the smaller but heavily developed water sheds. In this regard a study of the Ruhr area *Genossenschaften* that I made several years ago has been suggestive of possibilities.[19] The *Genossenschaften* are the only institutions in the world that have developed a far-reaching and integrated regional system for the management of water resources in an area where quality is the primary problem. Our studies hope to define to what extent an approach of this kind, based, hopefully, on more systematic methods of evaluation and design, could contribute to efficient achievement of water quality objectives in this country. Such studies also provide useful opportunities for developing the methods of systems analysis in the context of this important public management problem. I believe that a number of case studies along this general line in the varying regional circumstances of this country would make a very important contribution to the efficiency with which we manage and use our water resources in the future.

In connection with case studies of regional water management where quality is a major problem, I would like for illustrative purposes to comment further on a study being done by an RFF staff member[20] and to address the problems of planning in a larger basin.

18. These cases are the Potomac River Basin and the Miami Sub-Basin of the Ohio River Basin.

19. See A. Kneese, The Economics of Regional Water Quality Management, ch. 7 (Johns Hopkins Press for Resources for the Future, Inc. 1964).

20. Robert K. Davis.

The study largely utilizes data from the plan for development of water resources of the Potomac Basin, which has recently been presented by the Corps of Engineers and cooperating agencies.

The first stage of this study is devoted to the problem of determining an appropriate range of alternative outcomes, or a specific objective in a case like the Potomac, where the desirable outcomes having to do with water quality were not evaluated in monetary terms. To mention but one important example, the planned provision of storage for flow augmentation to improve water quality in the Potomac estuary is based upon the objective of maintaining a certain amount of dissolved oxygen with a specified probability. The prescribed level of dissolved oxygen and its required reliability were selected at the beginning of the planning process and a system was designed to achieve these essentially arbitrary objectives. It is entirely possible that had a slightly higher or lower standard for dissolved oxygen been chosen, the costs of attaining that level would have been much different than the costs of the actual plan. Thus, a systems analysis of the plan, including cost sensitivity tests of the proposed standards, is being conducted by using computer simulation. Cost sensitivity analysis is a kind of minimum economic analysis. It provides a minimum estimate of the value that must be attached to a specific improvement in water quality if the improvement is to be deemed worthwhile. A performance standard set without regard to cost, then followed by measures designed to attain it, unfortunately continues to be common practice in planning efforts.

Another problem being explored in this study is whether jurisdictional and institutional limitations may have prevented the Corps of Engineers from identifying the economically optimal system for achieving a given set of objectives. It appears, for example, that certain alternative ways of handling waste loads were not adequately analyzed, possibly because means of implementing them were not clearly at hand or political resistance was expected. This situation is exemplified, it appears, in the case of transporting wastes away from certain critical reaches of the estuary. Failure to incorporate the whole range of possible alternatives raises questions about the entire planning process as conventionally conducted; the same point has already been made with respect to the planning of recreation systems. One objective of comprehensive planning might well be the definition and evaluation of alternatives that may not be readily implemented under existing institutional circumstances to determine the costs of institutional and jurisdictional obstacles. This in itself would provide useful guidelines for assessing the importance of institutional change. One of the functions of Type I or "framework" planning by the federal agencies might be to generate information about alternatives with relative independence from any institutional or political restraints.

In the longer term the creation and appropriate development of efficient institutions must be deemed of far greater significance than the optimization of a particular physical system at a given point in time. Accordingly, efforts should be made to conduct economic research that illuminates the economic implications of various institutional forms. This largely uncultivated area is of the first order of importance.

VI

FLOODS

In the more highly developed regions, the control of flood damage is among the major aspects of water management. Also, flood control has received detailed and sophisticated economic study of benefits. Indeed, the Flood Control Act of 1936 enunciated a general welfare economics criterion when it indicated that federal projects should be considered justified if "the benefits to whomsoever they accrue exceed the costs."[21]

Population growth and urban development have produced an unprecedented occupation of flood plain lands. Consequently, estimates of average annual damage measured in constant dollars now exceed the levels that obtained prior to the initiation of the nationwide flood control program in 1936. It is now widely recognized that means other than the traditional structural protective measures may enter into an optimal system for controlling flood damages. This presents difficult problems for evaluation procedures and methods of implementation. While there have been substantial successes in the study of flood plain management and flood plain alternatives, particularly in the work carried forward under the directorship of Gilbert White at the University of Chicago,[22] there is still no firm basis for considering the full range of flood damage control tech-

21. 49 Stat. 1570 (1936), 33 U.S.C. § 701a (1964).

22. The following publications, all published by the Department of Geography of the University of Chicago, have resulted from this effort:

(1) G. F. White, Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States (1945).

niques or gauging the dynamic effects of various alternative control measures on investment and flood plain occupancy. One study[23] sponsored by RFF builds on the foundation laid by White and is aimed at developing a framework of analysis for explaining and predicting investments in flood plain land. More studies are needed to develop methods for establishing the actual comparative advantage of locating various different activities in flood plains. Studies of this kind should also help to shed light upon the question of how effective an inducement to industrial activity the protection of flood plain land can be in Appalachia or other depressed areas.

We must also learn to understand what managemnet institutions and instruments are appropriate for the control of flood damages. What are the proper regional institutions for taking a comprehensive view of alternatives for managing floods and flood plains, and how would these properly tie in with regional institutions established to manage water quality, recreation and general land use development? Is it essential that beneficiaries of protection, who presently have virtually no reimbursement obligations, bear some or all of the costs of structural measures if flood damage is to be managed optimally? If beneficiaries carry these costs and if flood information is improved, will land use regulation be essential?

VII

INLAND NAVIGATION

A major portion of the more than a billion dollar annual appropriation for rivers and harbors is still accounted for by the extension of inland waterways and the renovation and expansion of existing waterway capacity. In order to help improve knowledge and procedures in the field of designing and evaluating inland waterways, the

(2) G. F. White et al., Changes in Urban Occupance of Flood Plains in the United States (1958).

(3) F. C. Murphy, Regulating Flood-Plain Development (1958).

(4) J. R. Sheafer, Flood Proofing: An Element in a Flood Damage Reduction Program (1960).

(5) G. F. White et al., Papers on Flood Problems (1961).

(6) I. Burton, Types of Agricultural Occupance of Flood Plains in the United States (1962).

(7) R. W. Kates, Hazard and Choice Perception in Flood Plain Management (1962).

(8) G. F. White, Choice of Adjustment to Floods (1964).

23. The study is directed by Professor William Pendleton at the University of Pittsburgh.

Transportation Center at Northwestern University, under RFF sponsorship, has undertaken to analyze the demand for barge shipping, production and cost characteristics of bargeline operations, and the cost characteristics of pick-up and terminal operations. It is hoped this project will provide the basis for identifying specific commodities that can be transported most efficiently over various lengths of haul by inland waterways to form the basis for evaluation of savings over alternative methods of transport.[24] The study focuses upon bargeline transportation as such, and to realize the benefits of results that may follow the study, it will be necessary to understand the real costs of alternative modes of transportation. This is partciularly true of railways, where nominal rates rather than actual incremental costs have generally been used for comparative purposes in the evaluation of inland waterway projects. This may radically overstate the alternative cost of using railroads, and because alternative costs are used as the basis for computing benefits, the benefits of bargeline transportation may also be overstated. In specific instances other options, such as pipeline, may be relevant alternatives. Like the cases of flood control, water quality, and recreation, devising transportation systems that include inland navigation ultimately presents the problem of understanding an entire regional or super-regional economic system. Again the question arises: Unless the beneficiaries bear the costs of the various services provided, to what extent can such a regional system approach optimality?[25]

VIII

OPTIMUM SYSTEMS

Perhaps this is an appropriate place to discuss more generally what might be called "the problem of system optimization." This problem can be broadly, and somewhat arbitrarily, divided into three elements:

(1) The formal, logical, mathematical problem of choosing appropriate methods of calculation to discover an optimum when given the objectives to be achieved, cost and benefit information, and knowledge of the relevant technological, physical, chemical,

24. A publication has resulted: C. W. Howe, Process and Production Functions for Inland Waterway Transportation (Industrial Administration Institute Paper No. 65, Purdue Univ. 1964).

25. See I. K. Fox & O. C. Herfindahl, Attainment of Efficiency in Satisfying Demands for Water Resources (Reprint No. 46, Resources for the Future, Inc. 1964).

and biological relations. While this problem presents an interesting and important area of interdisciplinary research to which economists have made susbstantial contribution, I will not discuss it further because this is a major topic in Maynard Hufschmidt's contribution to the symposium.[26]

(2) The problem of devising appropriate tools for optimally coordinating decisions in a mixed system of public and private enterprises has already been indicated several times in the context of particular problems. Even should a public authority have rather far-reaching water resource management powers, it will, under our system of institutions, always be necessary to coordinate decisions directly under the control of the authority with decisions of managerially independent units, *i.e.*, waste dischargers, flood plain occupiers, irrigation water users, urban and industrial water users, users of navigation channels, and the like. Possible devices here would include administered prices, standards, and other means of non-price rationing. I will comment further upon this problem.

(3) The third aspect of the problem of system optimization is determining the optimal geographic unit and the optimum scope of powers for an authority designed to plan and operate water resource systems. In spite of the usual advice that a public authority should "internalize" externalities, one may hypothesize that in view of administrative and informational gathering costs it would not be optimal to trace each technological interdependency to its bitter end in defining a geographical managerial unit. An additional problem is whether authorities with a wide scope of powers and considerable autonomy could be counted on to act disinterestedly in the public interest. The matter of designing public managerial institutions would appear to be an extremely fruitful area of interdisciplinary research, involving economists, political scientists and engineers.

Some further commentary on point (2) seems in order because it has not been so widely discussed as the others. While one study[27] has hypothesized that one of the major ways to improve the performance of water resource development and use would be to lay greater emphasis upon identifying beneficiaries of projects and

26. Hufschmidt has been associated with the Harvard Water Program since its establishment in 1956; he is currently Director of Research. A major publication of the program is *Design of Water Resource Systems* (Harvard Univ. 1962); information on current research is contained in Hufschmidt's article in this symposium.

27. Fox & Herfindahl, *op. cit. supra* note 25.

assessing them with their costs, the problem of pricing many of the outputs of public water resources investment has received very little attention. Even the professional economics literature addressing water resources problems has tended to view questions of reimbursement and pricing as matters of equity rather than as an integral element in achieving an efficient system.

It may help to illuminate this problem to discuss it further in the context of water quality management. Important among the alternatives for managing water quality in highly developed areas are process and production adjustments leading to waste reclamation in industry, as well as treatment of sewage and industrial effluent. Measures yielding scale economies to numerous managerially independent enterprises in the region may also be available, including treatment of waste in large collective facilities, regulation of streamflow, temporary lagooning of wastes with discharge proportioned to streamflow, and various methods to enchance self-purification capacity of streams. Of these alternatives, some are very likely to be outside the jurisdiction of any central planning or management authority.

Even in the Ruhr area of Germany, where central planning and operation of a water resources management system are particularly advanced, the *Genossenschaften* have not assumed direct control over the design and operation of industrial processes. Instead, they apply a combination of minimum standards and effluent charges to control discharge. In most areas in the United States, direct control of quality management alternatives by public authorities internalizing externalities is likely to be much more limited. Unless we are to fall far short of achieving optimum systems and modes of operation under these circumstances, careful and informed use of indirect control measures will have to be made. For example, these may be effluent charges, an alternative likely to appeal to the economist, or effluent standards. In either case if the objective is system optimization, these procedures will have to be applied with a view to system costs imposed by the discharge; and these costs will, of course, be affected by hydrological and economic circumstances. Some work on this particular problem has been published,[28] but considerably more theoretical and empirical work on various direct and indirect means of influencing decisions bearing upon the efficiency of water resources systems is needed. I would judge this to be particularly true in the areas of flood control, navigation, and irrigation.

28. Kneese, *op. cit. supra* note 19.

IX

OTHER ECONOMIC PROBLEMS

It should perhaps be reiterated that this discussion of economic research problems is not intended to be comprehensive. The objective is to point to some of the frontiers of economic analysis with respect to water resources and, in passing, to note some of the work that RFF is sponsoring in these areas.

I would like to turn finally to two perhaps more esoteric problems in the economic analysis of water resources management. Both problems have been with us, and perceived, for a long time, but they have not yet been resolved in a completely satisfactory way.

The literature relative to public investment has revealed a wide range of disagreement among economists about the appropriate comparative evaluation of present and future benefits and costs from such investments. There is wide agreement among economists that rates of discount currently used by federal agencies in their evaluation of the deferred consequences of present investment are too low. The range of disagreement concerning appropriate rates is so large, however, that the present value of future benefit and cost flows would be radically altered, depending upon which recommendation is adopted. The influence of interest or discount rates on the benefits and costs of water resource projects has been illustrated a number of times, most recently by Irving Fox and Orris Herfindahl.[29] For the Corps of Engineers projects authorized in 1962, Fox and Herfindahl report that had rates of 4, 6 or 8 per cent been used, rather than the generally applied rate of 2⅝ per cent, the following percentages of initial gross investment would have a benefit-cost ratio of less than unity: 9, 64 and 80 per cent respectively.

The disagreement over rate stems from such issues as whether risk and uncertainty appropriately enter the rate of discount, to what extent imperfections of capital markets exist, whether there is an identifiable social rate of discount which differs from private rates of time preference and the marginal product of capital, and the appropriate way of handling reinvestment from public and alternative private investments. Some exceedingly complex formulations of investment criteria have been suggested to simultaneously account for reinvestment rates, social rates of discount, and private rates of return. However, questions remain about the appropriate-

29. Fox & Herfindahl, *op. cit. supra* note 25.

ness of all criteria that have been suggested. Resources for the Future is currently sponsoring a study of this range of questions.[30] This work should go a long way toward clarifying at least the logical aspects of the problem. Further ingenious effort will be required, however, to give empirical content to such questions as what is a meaningful social rate of time discount, how imperfect are capital markets, and from which margins of use are the resources for public water resources investment drawn (are they actually drawn from the private sector or from other public sectors where rates of return may differ greatly from private rates)?

Finally, some manner of appropriately handling risk and uncertainty is also a critical element in achieving efficient water resources investment. Risk, which economists define as the situation in which outcomes can be forecast but only in terms of a probability distribution, arises basically from the central role which variable hydrology plays in determining system costs and benefits. In risky situations probability distributions can be calculated and much can be said about rational rules in these situations. For example, the calculation of benefits from flood prevention has long been based on the mathematical expectation of damages avoided by a particular increment of protection. The mathematical expectation is statistically defined as the first moment of a probability distribution.

While there continue to be important possibilities for improving the calculation and use of mathemetical expectation, and perhaps higher moments of the probability distribution, the more difficult, and indeed very frustrating, problems are presented by uncertainty. Uncertainty arises from an inability to forecast technological, economic, and policy changes affecting outcomes even in a probabilistic sense.[31] Because all calculations of benefits and costs are based upon projections, uncertainty is a necessary element in all system planning.

Specific types of uncertainty may be particularly strong in some circumstances. My feeling is, for example, that uncertainty in the area of planning waste disposal systems is especially critical at the present time. The design of reservoirs to store water for releases during low flows for the purpose of waste dilution is based upon a projection of the present technology of waste treatment. This means that removing more than 85 or 90 per cent of the biochemical oxygen demand from effluents is considered infeasible.

30. Professor Kenneth Arrow of Stanford University is in charge of this study.

31. For a recent analysis of effects of uncertainty on the costs of Bureau of Reclamation projects, see E. Altouney, The Role of Uncertainties in the Economic Evaluation of Water Resource Projects (Stanford Univ. 1963).

If this level of treatment does not meet the standard set for water quality in the stream, then the augmentation of low flows is almost automatically "justified" under current procedures. Because the planned reservoirs are large durable investments, projections of waste loads are made for many years into the future, usually to the year 2010 under current planning arrangements. Now it happens that for the first time in our history we have really marshaled a concentrated attack on the problem of improving waste treatment. The Public Health Service and the National Institutes of Health have large intramural and extramural research programs under way in this area. The Advanced Waste Treatment Section of the Taft Sanitary Engineering Center in Cincinnati is investigating a wide range of improved removal procedures. It does not seem visionary to suppose that long before the year 2010 the technology of waste treatment will have changed radically. Predicting exactly how it will change is, of course, an impossibility. Thus appears the problem that I would call technological uncertainty.

An interesting and rather spectacular example of uncertainty associated with economic and policy changes occurred in planning for the development of the Potomac Basin. In 1944, a plan was presented for the development of the waters of the Potomac Basin, in which the primary purpose to be served by the several large impounding reservoirs in the plan was to generate hydroelectric power. In 1963, a new plan was presented in which hydropower plays no role at all. The difference in the two plans appears to arise in considerable measure from the large, and to some extent unforeseen, increase in urbanization and industrial growth in the basin and the accompanying demands for services, such as waste dilution, municipal water supply, and recreation.

There are no logically satisfactory decision rules for dealing with uncertainty. This is distressing because one may readily hypothesize that much greater errors in achieving the best use of water resources will arise from failures to predict technology and economic circumstances correctly, rather than from failure to measure current values accurately, or to find the best combination for a set of given values and currently feasible system components. An array of difficult questions concerning uncertainty must be addressed if our use of water resources is to improve. What, for example, would be the benefit from institutions that make it possible to view system planning as a continuing process? Would it be helpful to require that each project proposal be accompanied by a calculation of the present value of the net benefits forgone if the project were delayed for, say, ten years? Should alternative assumptions concerning possible alternative states of demand and technology accompany plans? Could we learn why forecasts went wrong and about other limitations of planning procedures by doing intense post-mortems on projects and planning efforts?

CONCLUSION

It would seem fair to say that applied economic research has had some of its most notable successes in the area of water resources planning and management. Still, as I trust this paper demonstrates, there are many difficult challenges ahead. Those responsible officials who must plan and operate water resource facilities and systems cannot wait until fully satisfactory answers are available to all the remaining problems. However, it is incumbent upon those in universities, in the foundations, in government, and especially those in the new water resources centers who are conducting and administering research, to press forward as rapidly as we can to provide meaningful guides to those engaged in planning and implementation if we are to improve efficiency in the use of our resources commensurate to the demands that are being placed upon them.