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## WATER QUALITY, A PROBLEM FOR THE ECONOMIST<sup>1</sup>

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IT IS with some diffidence that I approach a problem area which, with respect to private and public investment and to effective public policies, is one of the most significant underdeveloped areas in the economics of natural resources. This is true no less domestically than abroad. In the terminology of my assignment, this is the area of managing the quality of natural resources or, for short, the problem of quality management. I prefer this broader concept to the more usual term "pollution control."

### *Quality Management in Natural Resource Economics*

A few words need to be said about the meaning of quality in this context. It is well known that use of natural resources by man frequently does not involve an irreversible decrease of physical quantities of stocks and flows through consumption and transformation but, rather, a reversible decrease in suitability for *reuse*. For some important resources, such decrease of quality is restored through natural processes—provided that intensity of use is held within certain limits. Regardless of whether quality is restored by natural processes, man can prevent, reduce in degree or duration, or reverse a decrease of quality at the expense of some use benefits foregone or some additional costs incurred; he can do so even if a decrease of quality is due not to his own use but to natural causes, such as erosion and deposition. Thus, the problems of quality management are not merely technological but, to a large extent, economic and political.

Reuse is an especially intriguing problem for the economist because different uses of the same resource commonly have different effects on quality and, in turn, have different quality requirements. Thus, quality management has to deal with a multiple-use problem of a particular sort, namely, with the sequence of different uses over time. Some problems of the quantitative allocation of resources among different uses appear in a new light if differences in quality effects and quality requirements are taken into account.

The economics of quality management are significant problems for many natural resources. This paper is confined to water resources by assignment. A closely similar economic analysis, however, can be applied to other natural resources—especially to soil, air, and recreational resources.

All major water uses, except irrigation, are largely nonconsumptive. This is true for uses by households (domestic), manufacturing, including

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<sup>1</sup> Giannini Foundation Paper No. 212.

steam electric plants (industrial), transportation on rivers and canals, recreation (boating, swimming, fishing), hydroelectric plants, and, last but not least, waste disposal. Even in irrigation, less than two-thirds of total water use is consumptive—through evapo-transpiration. In arid and semiarid climates, at least one-third of total water use, and frequently more (depending on its quality and on the soil), is needed for leaching harmful salts into the ground water. Drainage of such ground water through streams and canals is becoming a crucial problem for the continuity of irrigated agriculture. The economic problems created by agricultural pollution are no less important than those created by industrial, domestic, and recreational pollution.

What was just said about quality effects and quality requirements of different uses is applicable especially to water resources. For example, some important industrial uses, such as cooling, have practically no quality requirements, and the quality effects are merely increases of temperature. But other industrial uses, for example, in the chemical industry, and most domestic uses have strict quality requirements, and the quality effects are great. Irrigation use has an intermediate position between these extremes.

In an economics of natural resource that focuses on use rates, on their complementarity, competitiveness, or neutrality in benefits and costs, and, especially, on the time aspects of these relations, reuse is conceptually integrated into the economic analysis. Such an analysis has been presented elsewhere.<sup>2</sup> It may be helpful, however, to restate here the main economic problems and conclusions with explicit reference to water quality management.

Only too often, water is treated in economic analysis as if physical quantities of a homogeneous commodity were under consideration. Concern is expressed over the increasing competition between agricultural and industrial uses even when they have different quality requirements and are, therefore, "noncompeting groups." In input-output analysis, technical coefficients of water use for different sectors—expressing acre-feet of water required per dollar output of product—are developed without taking into account differences among sectors in quality requirements and intersector reuse of water. Aggregate quantities "required" by all sectors are computed on this basis and projected. In linear programming studies of quantitative optima in water development and allocation, problems of waste disposal and reuse are neglected. Although the past and present extent of reuse is one of the least satisfactory parts of water statistics, it is certainly significant, not constant over time, and greatly affected by water policy.

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<sup>2</sup> Ciriacy-Wantrup, S. V., *Resource Conservation, Economics and Policies* (Berkeley: Univ. of Calif. Press, 1952), 395 p.

Referring to problems in quantitative water economics might create the impression that problems of quality management are less amenable to quantitative measurement. Such an impression is not justified. The semantics of the words "quantity" and "quality"—like that of many dichotomies—are unfortunate, and some possible confusion must be guarded against.

The technological aspects of water quality are no less amenable to precise quantitative measurement than the volume, weight, or flow rate usually employed to measure water quantity. Rather, different quantitative dimensions are involved when water quality is considered. These dimensions are measurable with a degree of precision not greatly different from the traditional dimensions. The "new" dimensions are water temperature, dissolved oxygen (D.O.), biochemical oxygen demand (B.O.D.), total dissolved solids (T.D.S.) in parts per million (ppm)—or as milligrams per liter (mg/l)—and many similar ones for particular dissolved solids—such as chlorides, toxins, synthetic organics—that are important for particular kinds of reuse.

Difficulties of quantitative measurement arise frequently when these dimensions are to be evaluated in social economics. If evaluation is one-dimensional, for example, in pecuniary terms, a problem of "quality" is present in the sense that precise quantitative measurement may become meaningless or misleading. This problem of the relevant degree of quantification in science is not peculiar to water quality management; it is present in all attempts to identify social optima in water development and allocation and has been discussed elsewhere.<sup>3</sup> We shall return later to the problems of evaluation in connection with the formulation of policy objectives in water quality management (Section 3).

Time does not permit going into the technological aspects of water quality management. The very complexity of these aspects makes the literature in this field of great interest to the economist. Suffice it to say that a thorough study of the technology of water quality management is a necessary condition for dealing with the economic and political problems associated with them. No attempt is made here to treat these problems exhaustively. They will be ordered according to their relevance for water policy. Emphasis will be placed on the reasons why in a market economy investment in water quality management has an inherent tendency to fall short of a conceptual social optimum and on the possibilities for water policy to remedy this situation.

The first step in this analysis is a study of the incidence of social costs and benefits in water quality management. This is the key economic prob-

<sup>3</sup> Ciriacy-Wantrup, "Projections of Water Requirements in the Economics of Water Policy," *J. Farm Econ.*, Vol. XLIII, No. 2, May 1961, and "Philosophy and Objectives of Watershed Policy," *Economics of Watershed Planning*, ed. Tolley, G. S. and Riggs, F. E. (Ames: Iowa State Univ. Press, 1961).

lem. We shall then proceed to an analysis of how the incidence problem is related to a conceptually and operationally helpful formulation of policy objectives.

### *Incidence of Social Costs and Benefits in Water Quality Management*

In a regulated market economy like that of this country, the extent to which decreases of water quality are taken into account as costs by planning units making production decisions that cause pollution, is determined not by the interplay of economic forces in the market place but by laws and similar social institutions. In other words, if economic forces alone were operative, the social costs of decreases in water quality would not be incident on the polluters but on the pollutees—if you permit. By the same token, the social benefits of pollution abatement would not accrue to the planning unit that could prevent pollution at the source. Water pollution has long been the classical example of real external economies and diseconomies.<sup>4</sup> By “real,” I mean externalities that are not merely income transfers among sectors of the economy through offsetting increases and decreases of values due to price changes. At least in degree, real external social costs and benefits are more important in water quality than in water quantity management. Several economic consequences are especially relevant for water policy.

First, at a given state of technological development, individual planning units—industrial firms, farms, households, cities, and public districts—select production functions without regard to the effects of quality, quantity, and timing of their discharge on the quality of receiving water resources, such as ground water, streams, lakes, and tide water. Timing needs to be stressed because, owing to variations of flow rate, temperature, dissolved oxygen, turbidity, and other conditions, water resources vary over time in their capacity to receive discharge. The term “production function” is interpreted here broadly. Households are regarded as processing firms using water for production. Some household production functions, for example, those involving detergents, have significant effects on the quality of discharge. Similarly, city sewer departments and public sewer districts may be regarded as processing firms with alternative production functions available to them for collecting, treating, and discharging sewage.

Second, and more important over time, planning units have no economic incentive to undertake and support research with the objective of pushing technological change into directions that would help to control their discharge in the interest of reuse by others. Experience in recent decades indicates that the potentialities for technological change in this

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<sup>4</sup>The term “spill-over effects” that has become popular recently adds nothing to the analysis.

area are great. The technology of waste treatment in this country and abroad has advanced in spite of a relatively small over-all research effort. One important direction of technological change which should be emphasized in the future is finding substitutes for especially harmful but stable materials that enter discharge. Some detergents and pesticides are examples. The industries producing these are on the front line of technological change and, in the past, have reacted effectively when private or public needs called for the development of new products. Another important direction of technological change in the future is reclamation of wastes into salable products. Fuel, fertilizer, feed, and fish are important by-products of modern sewage treatment plants in some European countries. A study we are making of water policy in Soviet Russia points to economic incentives through administered prices and large resulting investments for producing ethyl alcohol from the wastes of the pulp and paper industry.<sup>5</sup> Many wastes of the chemical and oil industries could be reclaimed with proper incentives. Pollution abatement is a joint product. All these industries are characterized by rapid technological change.

Third, a given standard of water quality which, as discussed in detail below, may be adopted as a policy objective for the water resources receiving discharge is not likely to be realized with minimum total social costs if quality management is not applied at the source; that is, *before* discharge. Technologically, the same quality standard can be realized through dilution and treatment *after* discharge. As an extreme, individual reusers can refine water at their intake to any degree of quality desired. But minimum total social cost combinations of technological alternatives for realizing a given standard of quality are usually unobtainable if discharge remains uncontrolled.

The three foregoing consequences could be avoided by inducing planning units to take external social costs into account in their decision making. The many laws and regulations that apply to quality, quantity, and timing of discharge have this objective. Economic soundness of this policy objective of water quality management depends on several important conditions.

First, when regulations regarding discharge are imposed in order to force planning units to take external costs into account, external benefits produced by such units should be considered. It is possible, for example, that costs necessitated by legal requirements regarding quality of discharge prevent a pulp and paper industry from locating in a certain region or bring about migration to other regions or force it out of business altogether. If such an industry creates external *net* economies, it may be in the interest of regional or national welfare that an appropriate portion

<sup>5</sup> This study is being undertaken by M. Gucovsky under a grant from Resources for the Future, Inc.

of the costs of discharge control be taken over by the public.

Second, the sound policy objective of forcing planning units to take external costs into account does not necessarily mean that each planning unit should be forced to control its own discharge. For some industrial firms and some farms, for example, dairies, this approach may be the one with minimum total social costs. For other industrial firms and most farms, the economies of scale of treatment plants and economies based on technological advantages in treating a discharge-mix from different industries will argue for unified collection and treatment at strategically located points of a river basin. In irrigated agriculture, large master drains known as wasteways take the place of unified collection and treatment of city sewage.<sup>6</sup> In unified water quality management, the economic incentive of internal costs may still be realized by distributing costs among individual planning units through a sewer service rate system based on studies of the effects of quantity, quality, and timing of individual discharges on the costs of collection, treatment, and disposal. Such rate systems exist in this country and abroad.<sup>7</sup> They deserve further refinement and general application. Frequent or, better still, continuous checking of discharges and of the quality of the receiving water resources is a prerequisite of an effective application and adjustment over time of such rate systems. A water intelligence service is one of the most important components of water quality management. Electronic recording and transmitting instruments are effective tools of such a service.<sup>8</sup> For households, however, checking of individual discharges would be too expensive. For households, therefore, economic incentives to change production functions must be applied at the manufacture and distribution stages. Several countries—among them, Great Britain and West Germany—are considering prohibition of manufacturing, or at least of domestic distribution, of some detergents.

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<sup>6</sup> Such a master drain is being proposed for the San Joaquin Valley in Calif. See: Calif., Dept. of Water Resources, Div. of Resources Planning, *Lower San Joaquin Valley Water Quality Investigation*, Div. of Resources Planning Bul. No. 89 (Sacramento, Dec. 1960).

<sup>7</sup> Laboon, John F. and Dougherty R. J., "Setting Fair Sewer Services Rates for Sewage and Industrial Wastes," *Wastes Engineering*, Vol. 31, No. 2, Feb. 1960, pp. 92-94 and 113. An even more elaborate rate system than the one discussed in this article for Allegheny County in Pa. is in use by the "Ruhrverband," the Metropolitan Water District responsible for the unified quality and quantity management of the water resources of the Ruhr in West Germany.

<sup>8</sup> To illustrate, the 1960 annual report of the Ohio River Valley Water Sanitation Commission mentions that they will have 40 electronic instruments located along the Ohio River. These will record and report data on dissolved oxygen, chloride content, hydrogen ion concentration, specific conductants, biochemical oxygen demand, temperature, and solar radiation. The Ohio River Valley Water Sanitation Commission is a regional authority in which nine states are cooperating. See: Ohio River Valley Water Sanitation Commission, *Chronicle of the 12th Year, 1960* (Cincinnati, 1961), p. 15.

Third, when attempting to force planning units to take external costs into account, one must recognize that cities, counties, public districts, and State and Federal agencies are in a different economic and legal position from private firms and farms with respect to decision making. Decision making in private planning units is sensitive to economic and legal incentives. The management of a city or county sewer department, on the other hand, may have the best understanding and intention to cooperate in the elimination of external costs, but investment decisions depend on city and county Governments. Financing of investment in pollution abatement is generally by bond issues, which usually require a two-thirds majority of the electorate. Local governments and electorates are not easily convinced that taxes should be increased for public resource development, the benefits of which will largely accrue to other communities. Furthermore, it is difficult to enforce laws and regulations against public bodies.<sup>9</sup> Some courts, for example, treat the right of a municipality to use streams for waste disposal as a public right that has priority over other water uses.<sup>10</sup> The system which is developing, therefore, in this country and abroad, is one of large-scale Federal and State grants, wherever possible on a matching basis, and of low-interest loans, to help local governments reduce on a voluntary basis the external costs of pollution caused by their jurisdictions.<sup>11</sup> Potentially, such Federal and State grants and loans could be used to coordinate quality management throughout a river basin. Efficiency in Government expenditures requires such coordination.

The last point leads me to a conclusion—or prediction if you like—which follows from the analysis of problems of incidence of costs and benefits just presented. I should like to submit that water quality management will become a stronger force toward unified river basin develop-

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<sup>9</sup> The same problem exists in air pollution. California had to enact a special law in 1961 to give the Bay Area Air Pollution Control District authority over State and municipal jurisdictions.

<sup>10</sup> Beuscher mentions a Wisconsin case in which an irrigation permit was denied because stream flow might be reduced to a point where it was not sufficient to dilute sewage from a downstream municipality. Beuscher, J. H., "Appropriation Water Law Elements in Riparian Doctrine States," *Buffalo Law Review*, Vol. 10, no. 3, Spring 1961.

<sup>11</sup> California started this system with a \$90 million grant in 1946 under the Construction and Employment Act. Under later legislation, a Water Pollution Control Fund was set up for the purpose of low-interest loans. See: Calif., *Statutes of Calif.* (1946-1947), pp. 30-39, "Construction and Employment Act"; Calif., *Statutes of Calif.* (1949), pp. 2793, 2794; Calif., *Statutes of Calif.* (1953), pp. 1361-1362.

In the Federal government, the 1956 Water Pollution Control Act was amended this year and appropriations increased to \$570 million. This bill fixes the Federal share of any single antipollution project at \$600,000 or 30 percent of the total cost, whichever is smaller. See: U. S., Public Laws, Statutes, etc., an act to amend the Federal Water Pollution Control Act to provide for a more effective program of water pollution control, Washington, D.C., July 24, 1961 (Public Law 87-88).

ment than water quantity management has proved up to now. In water quantity management, the incidence of costs and benefits is such that it is economical for groups of beneficiaries to undertake partial development themselves. Most of California water development took place on this basis. In water quality management, the polluters as well as the beneficiaries of pollution abatement must participate. On the other hand, through the economics of dilution, water quality management is intimately related to quantity management, especially storage. The most completely unified river basin I know of—that of the Ruhr, comprising the industrial heartland of Germany—is one with quantitatively abundant water resources in a humid region. The driving force for unified development came from the quality side. Some aspects of this example have a bearing on the formulation of policy objectives in water quality management. This problem will be considered next.

#### *Formulation of Policy Objectives in Water Quality Management*

At first glance, one might conclude from our discussion of the incidence problem that policy objectives in water quality management might be conceptualized as “the optimum waste disposal system” taking account of externalities, of alternatives in abatement, of interdependence with water quantity management, of cyclical and stochastic aspects, of uncertainty, and of changes over time in all of these elements. The term “watershed firm” or “basin firm” has become popular for the fictitious entity that optimizes. Some authors contend that the optimum waste disposal system can be quantitatively specified through formal programming techniques.

One may wonder a little about the helpfulness of such a formulation. The conclusion reached above, that the need for water quality management is a strong force toward unified river basin development, does not mean that policy objectives should be formulated within a basin framework. The two major policy objectives mentioned above—changes of industrial, agricultural, and household production functions and changes in the state of technology over time—transcend a river basin.

An optimizing basin firm is not a helpful construct for conceptualizing the relations between water policy and individual planning units. The basin firm cannot, even conceptually, take the place of individual planning units as optimizers. Neither can the basin firm undertake to optimize changes in technology in a conceptually meaningful way.<sup>12</sup>

In the past, economic incentives have operated to *increase* pollution (Section 2). Even if this influence were reversed through water policy along the lines suggested, there would be no assurance that all plan-

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<sup>12</sup> In programming, technology is included in the constraints and not in the objective functions.

ning units would respond to the same extent and at the same time. Serious types of pollution are caused by a single polluter sometimes during a very short time. In addition to this uncertainty, a change of economic incentives will increase uncertainties related to technological change. Thus, while a reversal of the direction in which economic incentives have operated in the past can be expected to solve a major part of the pollution problem over time, these incentives must be applied in such a way that a definite *minimum* response by individual planning units is assured. This, as we know, can be achieved through regulations regarding quantity, quality, and timing of individual discharges, through prohibition of certain production functions, through unified collection and treatment of wastes with appropriate distribution of costs, or through a combination of all three.

The question now arises: how far should water policy go with these measures? In other words, what is the particular minimum standard of quality in the receiving water that should be the policy objective? At present, this standard is determined on the basis of considerations in the fields of public health, sanitary engineering, and other applied natural sciences. Economic considerations come in by the back door in the political process through which quality standards are enacted in laws and regulations.

There is also some argument among experts in public health and sanitary engineering on whether emphasis should be on standards of quality in individual discharges or on standards of quality in the receiving water. Both types of standards are needed. As previously mentioned (Section 2), the former are usually the most economical means of obtaining the latter. If treatment is applied after discharge, varying degrees of treatment will be needed to conform with stream flow variations. Under these conditions, treatment plants cannot operate at maximum efficiency. For example, a plant designed to remove 90 percent of the B.O.D. will not operate efficiently when removing 50 percent of the B.O.D., and, of course, the reverse is impossible. Yet, variations in stream flow will be considerable, whereas the waste being treated will probably not vary greatly in degree of pollution at a particular treatment plant. Dilution, which has been the major tool of pollution abatement in the past, is of decreasing importance as the pollution problem increases. In the future, emphasis should be placed on other alternatives. This would avoid many of the problems posed by variations in stream flow.

Determination of a minimum quality standard in terms of economics is not simple. First, I should like to suggest that the distribution of the costs of maintaining such a standard—with a view to providing incentives in the two directions discussed—appears no less important than a particular standard and the quantitative level of the abatement investment associ-

ated with it. Second, while I do not believe that economics has the tools to specify an optimum standard which would change over time and which would be different for different streams and different sections of the same stream, economic arguments can be advanced for a minimum standard that would be stable over time for all normal streams and sections of streams. By "normal," I mean streams and sections of streams that are not deliberately set aside for waste disposal. The economic aspects of such stream specialization will be considered presently.

An economic argument for the general adoption of minimum standards as policy objectives in the field of natural resources has been offered elsewhere.<sup>13</sup> This argument is based on the need to make allowance for uncertainty, on the desirability of avoiding irreversibilities, and on the relatively small costs of minimum standards.

For the present purpose, additional arguments may be offered for a particular minimum standard of water quality. This standard is one that would maintain a healthy habitat for fish life. Such a standard can be defined with respect to the well-known quantitative dimensions of quality within a narrow range. Dissolved oxygen content, for example, is not to drop below 5 ppm.<sup>14</sup> In addition, fish life is a sensitive indicator for a wide spectrum of quality dimensions, the standards for which are not yet fully established. For example, the *cumulative* effect of certain pollutants on aquatic life is still uncertain.

From the viewpoint of the economist, the minimum standard suggested here does not avoid all arbitrary elements, but it defines a point of the external cost function of pollution that is of great economic interest. External cost functions of pollution are conspicuously discontinuous. In other words, over a certain range of pollution, external costs are small. At a critical level of pollution, however, external costs become large.

The critical point of discontinuity in pollution damage to fish is economically relevant not merely for commercial and sport fishing. Recreational uses, such as swimming, boating, water skiing, hiking along the shores, and mere aesthetic enjoyment, suffer critically if this minimum standard is not maintained. Likewise, agricultural uses and some natural and artificial processes of purification are seriously affected. Furthermore, this minimum standard has economic relevance for other uses. Although it is too low for domestic, municipal, and some industrial uses, costs of special treatment for these uses are decreased because the supplying water resources are free of toxic and other substances that are no less harmful to fish than to humans. On the other hand, it would be very

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<sup>13</sup> Ciriacy-Wantrup, *Resource Conservation*, . . . , Ch. 18, and "Conservation and Resource Programming," *Land Econ.*, Vol. 37, No. 2, May 1961.

<sup>14</sup> Most experts regard 4 ppm as the minimum (sublethal) figure for aquatic life and feel that at least 5 ppm is needed for normal reproduction.

costly to impose quality standards applicable to domestic water on water resources generally.

The "fishy" standard suggested here avoids the most difficult aspects of benefit-cost analysis, namely, the evaluation, in quantitative, pecuniary terms, of extramarket and collective benefits of pollution abatement. Economic calculation, however, is not pushed to the sidelines. The problem of realizing the standard with minimum total social costs remains, but it has become more manageable. General adoption of the minimum standard does not mean that a higher standard may not be economical for particular streams or sections of streams. The additional costs of a higher standard can be compared with the resulting additional benefits in each case. Here, also, the economic problem has become more manageable.

The last point brings me to the special case that was previously alluded to, namely, the zoning of a stream or a section thereof as open sewer without quality standard. For technological reasons, an open sewer has certain advantages over a closed one. The economics of such stream specialization are best discussed with reference to an actual example which I studied 2 years ago.

Water quality management in the Ruhr basin, referred to above (Section 2), is based on the concept of stream specialization. Water quality of the Ruhr is maintained at the minimum standard just discussed. A large portion of the wastes of the Ruhr basin, one of the largest industrial centers of the world, is transferred to the neighboring, parallel basin of the Emscher. The Emscher is intensively managed as a large, open sewer with up-to-date treatment plants at strategic points, making full use of the economies of scale. The Emscher basin, like that of the Ruhr, is under unified management. The two managements are so closely linked that functionally, although not legally, they can be regarded as one organization.

The results are impressive. The Ruhr and its man-made lakes form an attractive body of water that serves not only as the main water supply for the many municipalities and industrial complexes that make up the Ruhr district but also serves effectively the recreational needs of a large industrial population. All water sports are possible. The shores are intensively developed for recreation and residential purposes.

Stream specialization is sometimes recommended for this country. Some aspects of our example should be noted before it is imitated. Because of the small distances involved, the water supply and the recreational opportunities of the Ruhr basin are fully accessible to the Emscher basin—which has lost these assets. Further, a sewer system must discharge somewhere. The Emscher discharges into the Rhine, the large flow of which was for many years sufficient for dilution. In recent years, however, de-

mands on the Rhine for waste disposal have become so great that dilution is no longer sufficient. The problem is international in scope because the Rhine flows from Germany into Holland below the point of discharge of the Emscher. At this point a very large treatment plant is now under construction to bring the discharge from the sewer stream up to the quality of the receiving stream. Thus, before the concept of stream specialization is applied elsewhere, one should consider whether substitutes are available for those water uses which are irreversibly eliminated from the sewer stream and whether the discharge from the sewer stream will not create diseconomies that offset the economies made possible through stream specialization.

Time is running short, and I have not given a quantitative estimate of what the minimum standard suggested here would cost. I confess that there is no figure which I would regard as valid. The main reason is the uncertainty about the effects on this figure of changes in productive processes affecting the origin and disposal of wastes. Water policy itself will increase this uncertainty if it provides appropriate incentives along the lines suggested.

Fortunately, however, there are economists who are less skeptical than I am about long-range quantitative projections in water policy. Professor Wollman and his collaborators, for example, have undertaken such a study for the Select Committee on National Water Resources of the United States Senate.<sup>15</sup> They estimate that an additional abatement investment of \$99.6 billion will be needed in this country between their base year (1954) and the year 2000 to maintain a quality standard of 4 ppm of dissolved oxygen in all streams. In this estimate, the interdependence of quality and quantity management is taken into account. Annual costs for minimum total cost combinations of abatement measures will be \$2.4 billion by 1980 and \$4.4 billion by 2000.

These are impressive figures. Time does not permit reviewing the methodology employed. The figures may be helpful through dramatizing the magnitude of the economic problem and thereby making the people and their representatives more willing to accept public policies in water quality management. The professional economist, however, will be aware that the effectiveness of the abatement investment is not dependent entirely on its size. This paper tried to show that the key economic problem for this effectiveness is the provision of appropriate incentives—among others through distributing the cost of an abatement investment of whatever size. The institutional systems through which this distribution can be achieved are a subject for another paper.

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<sup>15</sup> U.S. Congress, Senate, Select Committee on National Water Resources, *Water Resources Activities in the U.S.*, 86th Cong., 2d Sess., 1960, Comm. Print No. 32, 131p.