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ECONOMIC INCENTIVES FOR IMPROVING MUNICIPAL WASTEWATER TREATMENT IN MINNESOTA

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ECONOMIC INCENTIVES FOR IMPROVING MUNICIPAL WASTEWATER TREATMENT IN MINNESOTA*

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INTRODUCTION

Although water quality continues to be a problem in the United States due to rising population and economic growth, substantial public efforts have been made to improve water quality. For the past 35 years, much federal legislation has been enacted in an attempt to manage the residuals discharged into the nation's waters. Government intervention has been necessary because market forces have failed to internalize the costs of residual disposal. This is because an upstream discharger of wastes does not take into account the costs its discharge imposes on downstream water uses.

This report approaches the problem of water quality from the standpoint of individual treatment plants.[1/] The main area of interest is the operation and maintenance of municipal wastewater treatment plants. The objectives of this study are: (1) to identify factors limiting the performance of treatment plants; (2) to evaluate the relationship between the Construction Grant Program and operation and maintenance (O&M); (3) to examine ways to provide incentives to maintain water quality and achieve minimum treatment cost; and (4) to provide the Minnesota Pollution Control Agency with information and suggestions on the feasibility of a state assistance program for the O&M of municipal wastewater treatment plants.

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*/ Scott Eckmann is a former research assistant while K. William Easter and John J. Waelti are professors in the Department of Agricultural and Applied Economics. We would like to thank Lee Martin, Glenn Nelson and Ron Dorf for their review of the report.

1/ The types of treatment plants of interest are activated sludge, trickling filter and stabilization ponds. For a discussion of how these processes work, see Clark, Viessman and Hammer, Water Supply and Pollution Control, 1971.

For many communities the treatment facilities are in place and operating. In a number of instances they have excess capacity which may never be used. This report suggests alternative approaches for allocating resources to water pollution control.

To fully understand the situation it is necessary to review Public Law 92-500, which has set the institutional framework of water pollution control for the past nine years. The examination of this law will lead to a discussion of the Construction Grant Program and its implications for resource allocation.

Public Law 92-500

As amended in 1972, the Federal Water Pollution Control Act (P.L. 92-500) now calls for several major actions on the part of both industry and municipalities. These actions can best be described by examining the national policies set forth by this law. The goals of the legislation which are central to this report are stated by Rodgers (1977), p. 355) as:

> (1) to provide federal financial assistance to construct publicly owned waste treatment works; (2) to develop and implement area-wide waste treatment management planning processes; (3) to initiate a major research and demonstration effort to develop technology necessary to eliminate the discharge of pollutants into the water; (4) to recognize the primary responsibilities of the states to plan the development and use of land and water resources.

The 1972 amendments represent a turning point in policy in that effluent standards (control of discharge at the source) became dominant over ambient standards (control of water quality in receiving waters). This marked a return to the policy set forth in the Refuse Act of 1899, which had stringent requirements concerning discharging wastes into navigable waters. The absolute nature of the Refuse Act is embodied in the goal of eliminating the discharge of pollutants into navigable by 1985. The ambient standards are a continuance of the 1965 Clean Water Act policies. The 1972 amendments represent a compromise between these two different approaches with the effluent standard receiving more emphasis.

A major feature of the amendments is provision of construction grants. The "best practicable technology" condition is used in both planning and as criteria for construction grants. The best practicable technology is one which provides an adequate level of treatment of waste at all point and nonpoint sources over the life of the treatment works. Rodgers (1977) asserts that this supports the argument that a municipality will meet the effluent standards conditioned upon their receiving grants to pay for the technology. This tie between the grant and the standard is very important for the purposes of this report and warrants closer examination.

The main purpose of the construction grant program is to fund municipal plants which will meet effluent standards in a cost effective manner (Arbuckle and Vandervær, 1979). As the more stringent standards of the 1972 amendments took effect, the need for financial assistance on the part of municipalities increased. To ensure that the effluent standards are met, municipalities must meet certain criteria in order to receive a grant. Rodgers (1977) states that the grants are given provided the municipality shows sufficient evidence that:

> (1) alternative waste management techniques have been studied and evaluated and the works proposed for grant assistance will provide for the application of the best practicable waste treatment technology over the life of the works consistent with the purpose of providing control of all point and nonpoint sources of pollution; (2) as appropriate, the works proposed for grant assistance will take into account and allow, to the extent practicable, the application of technology of a later date which will provide for the reclaiming or recycling of water or otherwise eliminate the discharge of pollutants.

Other criteria must also be satisfied to receive a construction grant. Among these are the requirements that a system of user charges be implemented so that those benefiting from the waste treatment service pay a proportionate share of the cost and competent operators must be employed. Also, the size and capacity of the facility must relate to the needs of the area it serves.[2/]

Limitations

There are several reasons why increasing treatment plant construction in the 60's and early 70's occurred simultaneously with declining water quality throughout the U.S. First, the existing cost-sharing rules induced a bias against the most efficient residual abatement techniques. This bias results in local communities acting in their own self interests, ignoring abatement techniques which are efficient from the social perspective. For example, techniques such as in-stream aeration, low flow augmentation and publicly owned individual septic tanks on private property are not eligible for federal assistance even though in certain situations they are the most socially efficient alternatives.

In addition to having cost sharing rules differ by treatment technology, they may also differ by type of cost. For example, cost sharing exists for capital costs, but not for O&M costs. This biases local choice in favor of capital intensive techniques. Marshall and Ruegg (1975) assert that grants are given for capital costs because they are easier to administer in that the total amount and the time of allocation is known.

[2/] For complete discussion of mechanics of the grant process, see Rodgers, Chapter 4, Section 4.10b, page 440.

Operation and Maintenance (O&M) grants given over time would be subject to uncontrolled economic conditions such as inflation, and would be an indefinite outflow from a grantor's budget. Given these factors, it is not surprising that the federal government has financed only capital costs.

The least cost condition for society for the production of residual abatement can be defined as:

$$\frac{\partial Q}{\partial T_1} \Big/ \frac{\partial Q}{\partial T_2} = \frac{P_1}{P_2},$$

where Q = units of output of residuals abated

T_1, T_2 = units of techniques 1 and 2

P_1, P_2 = social cost or price per unit of techniques 1 and 2

This necessary condition is derived from maximizing benefits to society, subject to a given budget constraint. The benefits are assumed to be a function of Q where $Q = Q(T_1, T_2)$. The constraint, S, is dependent on the prices, i.e. $S = P_1T_1 + P_2T_2$.

A community receiving a grant will attempt to minimize cost subject to its budget constraint and to a specified level of abatement. The difference occurs in the fact that for a given technique the community pays only a percentage, C_i, of the national cost (P_i). The least cost condition can now be expressed as:

$$\frac{\partial Q}{\partial T_1} \Big/ \frac{\partial Q}{\partial T_2} = \frac{C_1P_1}{C_2P_2}$$

If cost sharing is to induce communities to choose the socially efficient combination of techniques, then identical ($C_1=C_2$) percentage cost shares must apply to all techniques (Marshall and Ruegg, 1975). When these percentages are equal the community's minimizing condition equals society's least cost condition. It must also be remembered that fixed percentages must be applied to all types of costs so that this source of bias is also corrected for. The rule of equal percentage cost shares does not however yield the optimal percentage cost share. The rule does not address the problem of inducing communities to select the degree of treatment which coincides with the socially efficient scale of residual abatement.

The second shortcoming of the grant program is that effluent standards force the building of facilities which treat discharges at their source. This causes planners to overlook alternatives such as low flow augmentation and instream aeration. These alternatives are also overlooked because of the previously discussed bias away from techniques not eligible for federal monies.

Third, the requirement of secondary treatment for all facilities results in not enough treatment in some cases and excessive treatment in others. This problem is particularly relevant for rural communities as discussed by Young (1977). Often small communities may be better off with less costly, noncentral techniques such as septic tanks. As long as the amount of wastes generated is small, this method can be more efficient than the option of central collection and treatment.

Fourth, many states do not consistently distribute funds to those municipalities with the greatest need (Freeman, Haveman and Kneese, 1973).

Prior to P.L. 92-500, smaller communities received a disproportionate share of the grant money. This was, however, changed in 1972 as metropolitan areas became the prime recipient of grant money. Young (1977) found that small communities (less than 5,000), which are 12 percent of the urban population, received 9 percent of the total monies given in grants under P.L. 92-500. On the other hand, larger communities (greater than 25,000), which are 67 percent of the urban population, received 72 percent of the total monies given in grants. The increased burden on small communities stems mainly from economies of scale available to larger communities and the biases inherent in the cost sharing rules which induce communities away from ineligible technologies and cost categories.

The failure of the Construction Grant Program to provide the incentives necessary to ensure proper O&M has resulted in a great deal of discussion at the state level. This, along with the belief that well trained operators are the key to restoring efficient O&M, has resulted in the majority of states establishing certification programs for their operators. However, a certification program is only one component of a comprehensive water pollution control program. This study will examine an O&M subsidy program as another component of an overall program.

FACTORS LIMITING PLANT PERFORMANCE

Numerous factors have been found to be limiting improvements in waste treatment ranging from industrial wastes to inadequate plant design and operator training deficiencies. Hegg, et.al. (1978) identifies seven major barriers which have, in the past, caused inefficient plant operation: staffing deficiencies, operator salaries, design deficiencies, management techniques, industrial wastes, poor maintenance,, and inadequate budget. Hegg's study of 30 facilities identified 70 factors which contributed to inadequate plant performance. The highest ranking factor was "operator applications of concepts and testing to process control," i.e. the operator had general knowledge about wastewater treatment but was not correctly applying the appropriate principles. The factor ranking second was "wastewater treatment understanding," i.e. the operator had a general lack of knowledge of the business of wastewater treatment. These two factors imply a definite need for additional operator training.

Upon further investigation of these findings they found that all operators had the capability to improve plant performance (Hegg, et.al., 1978). Also, salaries and staff size were not significantly correlated with good or poor plant performance. The underutilization of operator capabilities was further highlighted by the third highest ranking factor -- improper technical guidance. The study concluded that the problems identified with the first two factors are not necessarily the fault of the operators, but may have been due to improper technical guidance from sources such as design engineers and state regulatory personnel.

Additional defense can be given to operators if one examines the fifth through tenth highest ranking factors limiting plant performance. These include such things as sludge-wasting capability, process flexibility, and process controllability -- all of which concern process design. These factors point to a conclusion which may have been overlooked. The problem is the failure, of those designing the plant, to create an efficient treatment facility (one which can operate a minimum cost and comply with its permitted level of residual discharge) and their inability to provide operators with proper technical guidance.

These conclusions are also reached by Sherrard and Kerri (1980), who concentrated specifically on operator training. They identify problems resulting from "bugs" in a new plant due to design, construction, and equipment sources. As effluent quality dropped, operators received the blame. In addition to the need for improved training, the authors found that improper technical guidance needed to be corrected.

Design Problems for Small Communities

For many small communities conventional central sewage systems result in overbuilt and overdesigned facilities. For small communities the collection system tends to be the most expensive component of the treatment process. This is due to the fact that homes are not clustered together and the cost of extending sewer lines out to isolated homes can be quite high.

Otis (1977) contends that a noncentral facility (several treatment facilities) has a number of disadvantages including: being untried, lacking public confidence, making a community's future growth more difficult and not being eligible for federal construction grant funds. He asserts, however, that it has important advantages which warrant further investigation. Advantages include: (1) the use of existing septic tank soil absorption systems instead of providing new service, (2) the service of isolated homes and clusters of homes rather than extending costly sewer lines out to them, (3) the protection of the ecological systems due to disposing of the wastes over a wider area, and (4) the lower cost treatment facilities can be constructed and may encourage communities to proceed with construction without waiting for federal construction grants.

According to the Environmental Protection Agency (EPA) Design Manual (1980) 25 percent of all United States housing units use onsite treatment and disposal systems. Examples of the types of systems used include septic tank soil absorption, septic tank/mound, septic tank effluent pump, holding tank, gravity sewers and land applications. These methods are for use by one home or a group of up to five or six homes isolated from the community. They often are built in conjunction with ponds, which serve the remaining population. The main concern with some of these onsite technologies is to locate them on suitable soils. In the U.S. only 32 percent of the total land area would be appropriate for systems employing the soil for treatment and/or disposal.

Government Action

The reaction of regulatory agencies at the state and federal levels has been to enact special purpose correction programs to overcome factors limiting plant performance (Hegg, et.al., 1978). Examples of these are the National Pollution Discharge Elimination System (NPDES) permit program, the Construction Grants Program and operator certification programs. The NPDES permit programs establish limitations on the quantity and type of discharges as well as obliging dischargers to monitor and report their discharging activities. The Construction Grants Program provides the funds to build the treatment plants necessary to meet the NPDES permit levels.

The operator training and certification programs are aimed at improving operator understanding of wastewater treatment and instilling good maintenance practices. Operator training and certification programs are implemented at the state level by agencies such as Pollution Control and Office of Environmental Manpower. Training enables operators to perform their job more efficiently, teaches them new skills and prepares them for promotions.[3/] In recent years several types of alternative programs and approaches have been suggested. Examples of these are: (1) A composite correction program as described by Hegg, et.al. (1978), (2) computerization and automation as discussed by Hadeed (1978), and (3) contracting out wastewater treatment as Great Falls, Montana has done. These alternatives deal directly with the factors limiting plant performance and in certain instances have proven very successful. This is not to say that they are the answer to achieving water quality in all cases. The point is that incentives are needed to ensure that municipalities consider all alternatives in planning for a new facility or in operating and maintaining an existing facility.

Conversations and correspondence with the MPCA officials and plant operators revealed that the majority of factors limiting performance discussed above occur at one time or another in Minnesota's plants. However, there seems to be a general feeling that Minnesota's plants are, in most cases, being operated effectively.

[3/] Optimum refers to achieving the water quality standards at minimum cost and employing inputs until their price is equal to the value of their contribution to production at the margin.

ECONOMICS OF POLLUTION CONTROL

Ideally, in approaching the problem of pollution control, all resources employed need to be considered. However, this is only possible in the long-run situations when all costs become variable. The long run refers to a planning horizon in which a firm or treatment facility is free to choose its plant capacity as well as the levels of all other inputs. After deciding on the level of output to produce, the firm then chooses its optimal plant capacity, within which the selection of other inputs (including capital) vary. The firm can rent as much capital as it requires, at its going market price. The particular distinction of interest here is that in the long run the least cost combination of inputs required to produce the chosen output level includes plant capacity. Once this level of capacity is chosen and the plant is constructed capital costs become fixed.

In the short run fixed costs exist which are independent of the output level. Fixed costs, rents for capital and land, are irrelevant for short run decision making, because they are contracted for in previous periods and there exists no way of avoiding their payment in the current period.[4/]

The distinction between the long and short run can be further explained with the concept of opportunity costs, i.e. the foregone value to society of the use of a resource in its next best alternative use. Kneese and Bower (1968) provide two reasons for this distinction. First,

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[4/] This assumes that the firm stays in business. They might avoid making the payments by declaring bankruptcy.

a treatment facility should be operated on the basis of current opportunity costs, because of the lumpy nature in which capital is introduced. Second, operating the facility according to variable costs will minimize costs when fluctuations in the hydrology of the river and meteorology of the geographic area are accounted for.

Kneese and Bower (1968) contend that it is necessary to take the short-run view because pollution control choices have been limited by the past decision to construct a treatment facility. With the facility in place, the character of opportunities foregone changes. The resources which went into its construction cannot be used in alternative activities, and their price cannot be considered an opportunity cost. The resources put into the plant for O&M have opportunity costs and it is these costs which are relevant for most decision making on residual discharges.

If a treatment plant was in the planning stage, then all capital costs would be included in the measure of opportunities foregone. This may be the case for communities with aging plants, whose performance and costs have become problems solely because of age. These communities are now in a position to re-evaluate the capacity of their plants. They know that the relevant output level will be water quality at no less than the effluent standards. They must choose the least costly combination of inputs, including capital, which will produce the appropriate level of water quality dictated by present and future effluent standards. It is only in a case such as this that capital has an opportunity cost and must be included in the resource allocating decision. However, the focus of this analysis is on the short-run examination of the O&M costs of existing treatment plants.

Economic Theory of Waste Treatment

The wastewater treatment plant will be assumed to behave as a competitive firm that minimizes cost and discharges an effluent, which complies with its NPDES permit. The output of the "firm" is water quality or the amount of BOD discharged.[5/] Knapp (1978) states that cost minimization represents a reasonable behavior under perfect competition for the following reasons. First, there are budgeting pressures from city hall which encourage operators to keep costs as low as possible. Second, the population which the plant serves does not like increases in their user rates. Minimizing costs helps to keep user rates from rising. Third, as the treatment plant becomes more costly to operate and user charges rise, substitutes such as onsite systems (septic tanks/soil absorption) become more economical. To the extent that people would leave the central system in favor of alternatives this could encourage the operator to minimize costs.[6/]

In the usual perfectly competitive case the firm operates where price (P) equals marginal cost (MC). For a waste treatment plant, however, price is not easily observable or determined because the output, water quality, is a public good for which no market exists. Price should repre-

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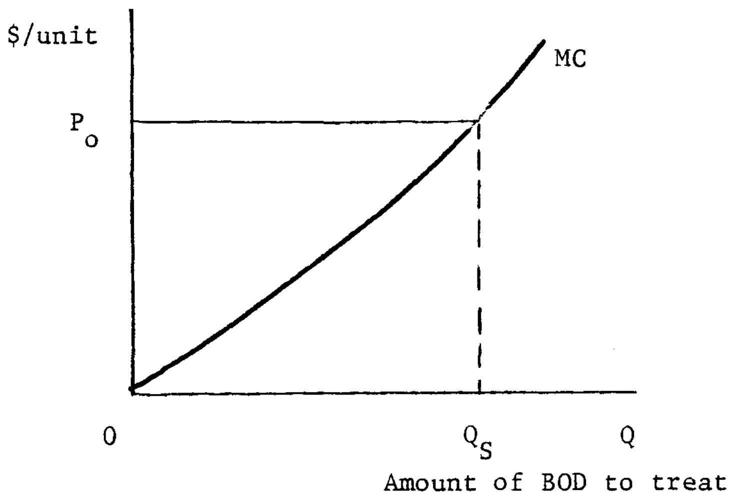
[5/] BOD (biochemical oxygen demand) measures the amount of oxygen required by bacteria in the decomposition of organic matter under aerobic conditions. This is a common indicator of water quality and is measured in mg/l (milligrams per liter).

[6/] The literature on bureaucracy would lead one to expect that the operator of a plant will exploit to some degree the monopoly position. Thus, a cost minimizing behavior is likely an oversimplification of the actual situation. This would be particularly true if the operator is the only one in the city that understand the plant's operation.

FIGURE 1. Marginal Cost of Treatment as a Function of the Quantity of Waste to Treat



sent the marginal willingness to pay for water quality by those people who use the water involved. Instead of determining the price through analysis of the demand side, we can use the water quality standards. For example, in Figure 1, if the standard is Q_S, then the intersection of Q_S with MC yields the appropriate price, P_o.

Market Failures

In the case of water pollution, externalities can arise from two sources: (1) the lack of a market in which water quality can be priced, and (2) the public good nature of our waterways.[7/] In the case of a

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[7/] Mishan (1971) states an externality has occurred when the value of a production or consumption function depends directly on the actions of others. The effect on another decision maker is an unintended result of some normal market activity. For a thorough discussion of externalities and their sources, see Dales (1968, pp. 791-804) and Mishan (1971, pp. 1-26).

wastewater treatment plant the municipality and state have chosen this particular use for the given body of water. In this respect they have a right to discharge, but the right is limited by water quality standards. The objective of these standards is to maintain quality to ensure that amenity uses will remain possible in downstream locations. When a wastewater treatment plant fails to meet the standard, excessive wastes result in externalities to other users of the water. The amount of discharge allowed was determined by biologists and engineers so that both uses, waste discharge and amenity, could coexist. The problem we are concerned with is when externalities rise above the legal level set by water quality standards.

Alternative Solutions to Externalities

There are six alternatives for correcting externalities which have received extensive coverage in the literature. These alternatives are prohibition, regulation, bargaining, charges, subsidies, and a pollution rights market.[8/] The two solutions considered in this study are charges and subsidies.

Most authors have concluded that the charge is favored, because of the inherent disadvantages in a subsidy solution (Kneese and Bower (1968); Seneca and Taussig (1974); Dales (1968) and Freeman, Haveman and Kneese (1973). The disadvantages of a subsidy include: (1) the surrender of property rights to the discharger; (2) the creation of incentives to generate wastes if costs of abating or treating residuals are less than

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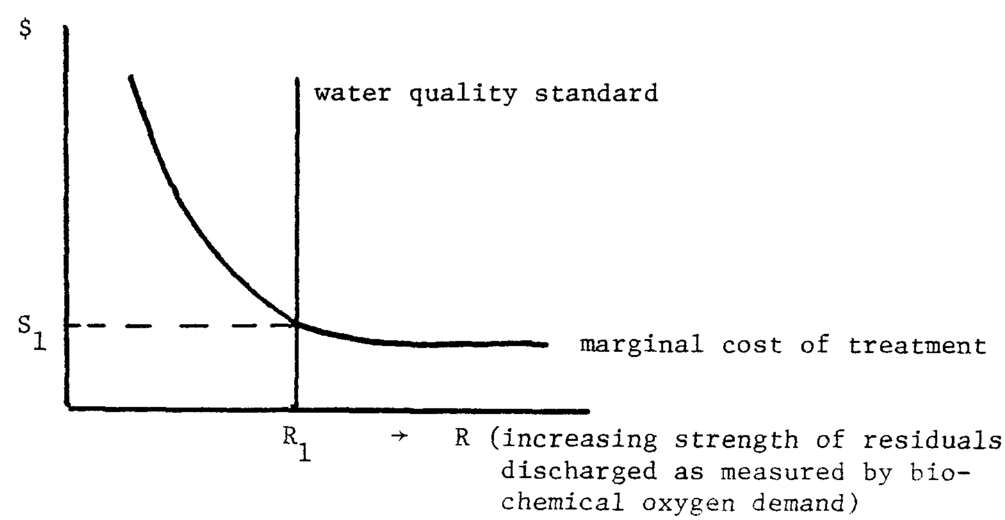
[8/] For a discussion of these alternatives refer to Mishan (1971), Freeman, Haveman and Kneese (1973), Coase (1960) and Dales (1968).

the per unit waste subsidy; (3) the tendency for the polluter to treat residual reduction as a potential marketable commodity; (4) the fact that a subsidy must be offset by increases in taxes and/or decreases in government purchases elsewhere; and (5) the information required to estimate the marginal benefits of a decline in discharges.

The fact that the "firm" in this case is a public wastewater treatment plant helps eliminate several of the above disadvantages. For example, people will not be able to go into the waste-making business as long as the output is water quality. Plants would receive a subsidy as water quality improves, i.e. as the amount of residual produced as a by-product declines. This is due to the inverse relationship between water quality and residuals.

The approach to be used is taken from Baumol (1972). A given water quality standard will be achieved using the incentives provided by a subsidy instead of an abatement charge. Figure 2 below illustrates the correct subsidy, assuming that the water quality standard is set at the optimal rate.

FIGURE 2. Marginal Treatment Cost as a Function of Residual Discharged by the Treatment Plant



The subsidy, S_1, is the appropriate level because it is equated to the marginal cost (MC) of treatment at the point where the water quality standard is met. The MC can be viewed as an aggregate function for a given stream or lake. Each individual treatment facility on the stream or lake will receive a subsidy for reductions which will lead, in the aggregate, to concentrations of residuals of R_1 and lower. This procedure does not necessarily result in an optimum as far as social welfare is concerned. It does, however, yield a workable system given our limited availability of information. The standard once set could be subject to change. If it is believed that the marginal benefits from treatment exceed the marginal costs (MB > MC), then the standard could be lowered, i.e. made more stringent. The subsidy may also need to be varied to reflect changing water conditions. Treatment facilities are likely to face conditions of low flow where storage of wastes becomes necessary. During these periods, higher subsidies may be needed to give plants the incentive to store wastes and to avoid excessive discharges.

ALTERNATIVE WASTE TREATMENT SUBSIDIES

Four alternative operation and maintenance (O&M) subsidies are estimated for Minnesota's outstate treatment plants. Since the subsidies are based on O&M costs, the first step is to determine these costs by plant type. One approach is to estimate O&M costs as a function of input prices and the output level. An alternative approach is to estimate O&M costs as a function of physical parameters, such as flow, influent and effluent.

The cost functions are then used to calculate the different levels of O&M subsidies. First is a subsidy based on the extra cost of meeting or being below permit levels with costs estimated as a function of input prices and BOD level. The second subsidy is equal to the extra cost of meeting or being below permit levels with costs as a function of physical parameters. The last two subsidies are based on plant size using the two different cost estimates. The latter approach is similar to the one used in New York State (State Proposal). New York pays a percentage of the O&M cost if a plant meets water quality standards and has a qualified operator.

Two sets of data are used to estimate waste treatment costs and subsidies. First is the data on waste treatment costs and input prices obtained in a 1980 mail survey conducted by the authors. Data was obtained for both the annual costs and the per-unit prices of each major factor of production, i.e. labor, chemicals, electricity and maintenance. They are used to estimate the relationship between input prices, output level, and variable treatment costs. The second data set is from the 1974 survey of waste treatment costs conducted by the MPCA and the 1977 MPCA performance studies. The 1974 costs are inflated to 1980 to make them comparable with the first data set.[9/] Waste treatment costs are estimated as a function of physical parameters (flow, strength of effluent, etc.) from the second data set.

[9/] Based on the construction cost index, the implicit price deflator and the Department of Labor statistics, the waste treatment costs were increased 12 percent annually.

Subsidy Based on Input Prices

To obtain data on input prices, a mail survey was sent to 417 treatment plants. The list of municipal plants was obtained from the 1974 survey conducted by the Minnesota Pollution Control Agency. The mail survey was designed to obtain the per unit prices and annual costs of labor, chemicals, electricity, and maintenance. The total variable cost figures are the sum of the annual costs for the four inputs. This will, for most plants, represent 80 percent or more of the actual total variable cost of the plant. Costs such as telephone, outside contracts and a number of small miscellaneous items were not included.

The wage for labor includes fringe benefits such as insurance, vacation and sick leave. The electrical rate represents the energy charge portion (charge per KWH used) of an electric bill. For those plants subject to the fixed demand charges, it is assumed that this is part of the fixed cost of operating and is not under the control of the operator. Also, the fuel adjustment charge which varies monthly depending on whether fuel costs to the electric utilities are rising or falling was not included. The fuel adjustment charges for 1980 were not very large (less than 1¢/KWH) and their omission should not significantly alter the analysis. The per unit cost of maintenance creates some problems. The need for maintenance arises because of the initial capital cost. The operators can practice a certain degree of preventive maintenance, but unexpected things sometimes occur which takes the level of maintenance expenditures out of their control. It will be included in the analysis, because the study of the New York program mentioned this item as possibly becoming eligible for aid in the future.

As with all surveys, there is a potential for inaccurate answers. Answers which appeared unlikely were checked by phone calls to the facility operator, town clerk, chemical companies and electric utilities. This was done for approximately 10 percent of the 217 replies. The greatest misunderstanding originated with the electrical rates, due mainly to a general lack of knowledge about the rates. Often those answering the survey knew the total electric bill, but made errors concerning the appropriate rate schedule. The errors were corrected by talking directly with the utility companies.

An additional source of error was the way the question on maintenance costs was answered. The question called for an average cost over a number of years. It was left to the respondent to choose the time period and compute the average. An average was requested because in any one year, a plant can have excessive maintenance costs if machinery and parts happen to wear out. By taking an average the extremes would be reduced. Unfortunately, many people merely gave an annual figure for 1979 or 1980. The small magnitude of the maintenance cost, however, will most likely make this error an insignificant one.

The source of output data, i.e. BOD (mg/l), is the monitoring records of the MPCA. These figures represent the average monthly discharge for 1980. It will be assumed that these figures are accurate, even though some error in their measurement and recording could undoubtedly be possible.

From the total of 417 surveys sent, 52 percent were returned. Out of these 217 replies only 188 were usable. A number of the 217 original replies lacked information on maintenance and electrical power and, although attempts were made to correct these deficiencies, not all of the problems were remedied.

The 188 surveys are grouped according to facility type, e.g., stabilization pond (64), trickling filter (70) and activated sludge (54).[10/] This division is important because the problems faced under each facility type are different. A variable which is of primary importance for one type may be insignificant for another. For example, chemicals are much more

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[10/] The activated sludge process consists of micro- and macro-organisms feeding on the colloidal and dissolved organic solids contained in the wastewater. MPCA (1976) describes the process as organisms breaking down the organic solids into energy, new cells, and single compounds such as carbon dioxide and water. This takes place in an aeration tank, where the biological life develops into a large brownish floc-like substance known as activated sludge. For best results there must be enough oxygen in the tank, pH should be close to neutral, temperature should be relatively constant and toxic substances should be absent.

MPCA (1976) describes the trickling filter process as consisting of a bed of crushed rock, slag, fieldstone, or a plastic medium which is coated with a biological film. The effluent is sprayed over this bed so that biological growth breaks down the organic material in the effluent. This organic material is converted into carbon dioxide and water. Some of the biological growth is washed off the bed and settles with partially decomposed organic material in a final clarifier. For a high rate of waste treatment the wastewater is diluted with a recirculation flow before being sprayed on the bed. For an efficient operation this process requires a continuous supply of oxygen and a high wastewater temperature.

The stabilization pond is essentially a flat bottomed pond surrounded by an earthen dike (Clark, Viersman and Hammer (1971)). The pond is approximately 7 feet deep, with the dike extending another 3 feet above the high water level. The bottom and dikes are often sealed with clay. Large ponds, 6 acres and over, are usually divided into individually operated cells. Bacteria and algae interact in the ponds in a symbiotic cycle, resulting in the stabilization of wastewater. As the algae and bacteria continue their actions on the wastewater, the unstable organic matter is converted into a more stable algae mass. The solids such as sludge and algae mass settle to the bottom of the pond where the anaerobic conditions result in decomposition of this thin layer of sludge. Consequently, there is little or no sludge disposal problems, discharges are easily controlled and energy from the sun is used.

important for activated sludge plants than for ponds. An F-test was conducted to test the null hypothesis that the data set as a whole yields a better explanation of the variation in total variable cost (TVC) than the explanation provided by separating the data into three subsets (alternative hypothesis).[11] The F-test confirms our supposition that the data should be separated into three subsets, according to technology. The sample is not meant to be representative of plants operated by the Metropolitan Waste Control Commission and the Western Lake Superior Sanitary District.

Cost Functions Based on Input Prices

The costs of waste treatment are estimated for each of the three types of plants using the least squares procedure.[12] The computer package used is MULTREG by Weisberg (1979). The following variables were used to estimate the total variable cost of O&M (1980 dollars): labor wage W_1 (\$/hr); chemical price W_2 (\$/lb), maintenance costs W_3 (\$/gal), electricity price W_4 (\$/KWH), and quantity of BOD discharged Q (mg/l).

Total variable costs will be a function of the four inputs and the output measured by the BOD discharge. These are the primary fac-

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[11] The F statistic is

$$\frac{(161.943 - 134.055/(181 - 166)}{134.055/166} = 2.302$$

where 134.055 is the pooled residual sum of squares for the alternative hypothesis. According to the F-test the null hypothesis is rejected at the 99% significance level, where F(15,181) = 2.16.

[12] For a discussion of the underlying model and assumptions used in least squares see Sanford Weisberg, Applied Linear Regression (New York: John Wiley and Sons, 1980), Chapters 3, 5, 7, and 8.

tors that should cause changes in TVC for a given set of waste treatment plants. When factor prices increase, the TVC should increase. When the output increases, i.e. improved water quality, TVC should increase (see Figure 1). However, our measure of output is not water quality but just the opposite, pollution (BOD). Therefore when BOD increases, TVC should decrease. In other words, we spend less on treatment and just increase our discharge of BOD (see Figure 2). This means our output of water quality is lower and the TVC is lower.

An analysis of the data suggested that the relationship between the dependent and independent variable had a log form. In addition, the values of the dependent variable (TVC) exhibit a large range. The Box-Cox family of transformations indicated that the natural log of the dependent variable would reduce this variability and restore constant variance to the error terms. Screening of various functional forms also determined that the natural log form provided the best data fit for all three plant types.

$$\text{Ln } Y = a - b_Q \text{LnQ} + b_1 \text{LnW}_1 + b_2 \text{LnW}_2 + b_3 \text{LnW}_3 + b_4 \text{LnW}_4$$

Table 1 summarizes the regression coefficients and the t statistics for the three regressions.

The labor wage is the most important explanatory variable in the regressions, while the cost of maintenance is never significant. Those variables which were not significant were kept in the analysis to provide consistent models for all three plants. In addition, even with five regressors the models were not unwieldy.

An important concern in the analysis was the possibility of multi-collinearity. The correlation coefficients indicated that the degree of multicollinearity is low. Other tests such as regressing the independent variables on one another and computing the condition number also failed to identify any serious multicollinearity.[13/]

The highest correlation is between the natural log of BOD discharged and the natural log of the labor wage, for the stabilization ponds. For the other two plant types the largest correlations occur between labor wage and the cost of maintenance. This may suggest why the cost of maintenance is so insignificant. Some of the explanation the maintenance cost carries is in its relationship with labor wage. This is most evident in the case of the trickling filter where the t statistic of labor is very large, while that of maintenance is quite small.

In evaluating the estimated relationship, the signs of the regression coefficients are expected to be positive or negative in each case based on how the factor prices and the output level affect the total variable cost of O&M. One would expect that as residual discharge increases, the plant is treating less and using less inputs, which should reduce the total variable costs. This indicates that the expected sign of the BOD coefficient is negative. In contrast as the factor input prices rise, the total variable costs should rise, but at a decreasing rate. This implies the signs of four input coefficients should be positive.

In the estimated equations in Table 1, there are several violations in expected signs.[14/] The only significant variable with an apparent

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[13/] Ibid., p. 178.

[14/] The violations of expected sign may be due to correlation among the variables as well as which variables are included in the model. Although the analysis did not indicate the existence of harmful multicollinearity, it may still have altered the signs of the estimated parameters (Weisberg, 1980).

TABLE 1. Regression of the Variable Cost of Waste Treatment on Input Prices by Plant Type

Regressors +	Activated Sludge Coefficients	Activated Sludge t Statistics	Trickling Filter Coefficients	Trickling Filter t Statistics	Stabilization Pond Coefficients	Stabilization Pond t Statistics
Constant	9.296	7.84**	5.594	4.39**	8.333	7.00**
BOD	-.207	-1.79*	-.170	-1.22	.095	2.73**
Labor	1.052	2.21**	2.836	7.30**	1.487	2.97**
Chemicals	-.004	-0.05	-.037	-0.55	.075	2.02**
Maintenance	-.088	-1.04	.054	0.57	.097	1.21
Electricity	.322	2.51**	-.119	-1.06	.119	2.14**
R^2		.281		.522		.398

+ All variables are in natural log form

* Denotes statistical significance at the level $\alpha < .10$ (90%).

** Denotes statistical significance at the level $\alpha < 0.05$ (95%).

wrong sign is the positive coefficient for the amount of BOD discharged for the stabilization ponds. The reason for the positive sign is the process itself. The average pond does not discharge as many times per year as the other two plant types. This is because the wastewater remains in the pond usually not needing much in material or labor inputs. An increase in costs occurs at times of discharge, thereby raising costs as more effluent is discharged. This means that an increased BOD discharge is not associated with lower treatment cost for the stabilization ponds. Consequently, for stabilization ponds, BOD discharge turns out not to be a good measure of output. A better measure of output might have been the amount of influent or flow received per unit of time. Note that the cost curves based on physical parameters show that TVC are positively related to flow of waste water entering stabilization ponds.

The main purpose of estimating these equations is to predict values of the dependent variable based on given values of the independent variables. These predictions will not be exact due to the existence of measurement error and/or unidentified independent variables. As can be seen by the values of R^2 for each plant type, the independent variables explain only 28 percent to 52 percent of the variation in total variable cost. Even with this uncertainty in the estimates, the predicted values can be considered statistically reliable as long as the functional form of the equation is correct. As a safeguard, however, Weisberg (1980) asserts that over limited ranges of parameter values many functional forms behave in the same manner.

In addition not all of the conditions needed to verify the procedures for defining cost curves are met. This indicates that the estimated relationships are just that -- relationships. They are not well defined cost functions. This is a further reason to restrict our use of them to predicting values of total variable costs for certain values of BOD and prices.[15/] It also suggests that these functions will only provide order of magnitude estimates. Better defined functions will be required before they can be considered for estimating actual subsidies.

Estimated Subsidy (Input Prices)

The proposed O&M subsidy, for purposes of this analysis, will be tied directly to the effluent discharge of each treatment plant to provide a monetary incentive to reduce pollution. The object of awarding the subsidy is to achieve levels of discharge at or below the plant's NPDES* permit level. Municipalities with plants operating above the permit level would obtain a subsidy equal to the cost of reducing their discharge to the permit level. They would obtain this subsidy once discharges reached the permit level. For those municipalities with plants already operating with discharges below their permit level, the subsidy would be to encourage them to continue at the low level. To do this the subsidy would be equal to the cost of reducing the waste load from the permit level

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15/ In order to apply observed results to predict future values, additional assumptions about the behavior of future values compared to the behavior of the existing data must be made. This is important if any extrapolation is to be done. Extrapolation is predicting values for cases with values of the independent variables outside the range of the actual data. It will be assumed that the future independent variables will have the same relationship with each other and with the total variable cost as the present data does. Also the relative importance of each in explaining the variability of total variable cost will be the same.

*National Pollution Discharge Elimination System.

to their current low level. All municipalities are eligible for a subsidy, because exclusion of those with plants already below the permit level will change the incentive structure of the program. For example, if only municipalities with plants not meeting the standard are eligible, those with plants discharging at or below permit levels may decide to discharge above legal limits to become eligible for the subsidy in the future. Such a system would produce the wrong incentives.

The estimated equations along with knowledge of the permit levels for each plant are used to estimate the appropriate subsidy for individual municipalities. For an example of a subsidy for those with discharges above permit levels, the city of Vermillion had, in 1980, an average monthly BOD discharge of 8 mg/l. Their permit allows them to discharge 25 mg/l BOD. The proposed subsidy would be equal to the total variable cost (TVC) involved in reducing the BOD discharged from 25 to 8 mg/l. The payment is computed by substituting Vermillion's actual input prices and BOD discharged (8 mg/l) into the estimated equation for the activated sludge plants. This yields an estimate of their TVC of $46,684. The same computation is done using the permit level (25 mg/l) instead of 8 mg/l for the BOD variable. The estimated TVC is $36,858. Subtracting these two values (46,684 - 36,858 = $9,826) provides the estimated extra treatment cost for Vermillion of lowering the discharge from 25 mg/l to 8 mg/l BOD. This $9,826 would then be the payment to Vermillion if they continued at the 8 mg/l BOD discharge level.

In the case of Pine River, which was not meeting its standard, the method of calculating the subsidy is similar. While Vermillion's subsidy would be a reward for discharging below their permit level, Pine River's payment would be for discharging at their permit level. Pine River discharged 47 mg/l BOD (monthly average for 1980), but their permit level was 25 mg/l. Their subsidy would be provided only if they improved performance and reach the permit level of discharge. Pine River's actual prices and BOD discharge (47 mg/l) are substituted into the estimated equation, in this case trickling filter, to obtain their current TVC. Their permit level (25 mg/l) is then substituted for the actual level of BOD and the expected TVC is estimated. The difference in TVC is $2,300 which would be the subsidy to Pine River once they reached the permit level. This procedure is done for all plants and the individual subsidies are summed within each plant type according to size. The results presented in Table 2 assume the situation as it was in 1980.

Several important observations can be made from Table 2. First, within each group it is the municipalities with the smaller plants, with design capacity below .5 million gallons per day (MGD), which are most likely to violate their permit level of discharge. Of the 188 total treatment plants, 155 of them are below .5 million gallons. Out of these 155 plants, 18 percent violate their permit levels of discharge. In contrast, only 4 of the 33 larger plants were above their permit levels. This supports the growing belief that municipalities with smaller plants are more likely to require assistance, technical and financial, than do the larger plants.

Second, there are relatively few plants within each group which fail to comply with their permit levels. Specifically, 81.5 percent of activated sludge plants, 70.3 percent of trickling filter plants and 95.7 percent of stabilization ponds are successful in discharging BOD effluent within the level set forth in their permits.

TABLE 2

SUBSIDY BASED ON INPUT PRICES

SIZE MGD	NUMBER PLANTS	PERCENTAGE COMPLYING WITH PERMIT	TOTAL SUBSIDY	AVERAGE SUBSIDY PER PLANT
Activated Sludge:				
< .5	42	80.6%	$136,533	$ 3,251
.5 - 1.0	4	100.0	68,893	17,223
1.0 - 10.0	6	83.3	56,129	9,355
> 10.0	2	50.0	11,511	5,756
	54	81.5	$335,047	$ 6,205
Trickling Filter:				
< .5	48	64.6%	$118,129	$ 2,461
.5 - 1.0	7	71.4	32,777	4,682
1.0 - 10.0	9	100.0	39,701	4,411
> 10.0	-	--	--	--
	64	70.3	$190,607	$ 2,978
Stabilization Pond:				
< .5	65	95.4%	$253,688	$ 3,903
.5 - 1.0	3	100.0	3,600	1,200
1.0 - 10.0	2	100.0	3,563	1,782
> 10.0	-	--	--	--
	70	95.7	$260,851	$ 3,726

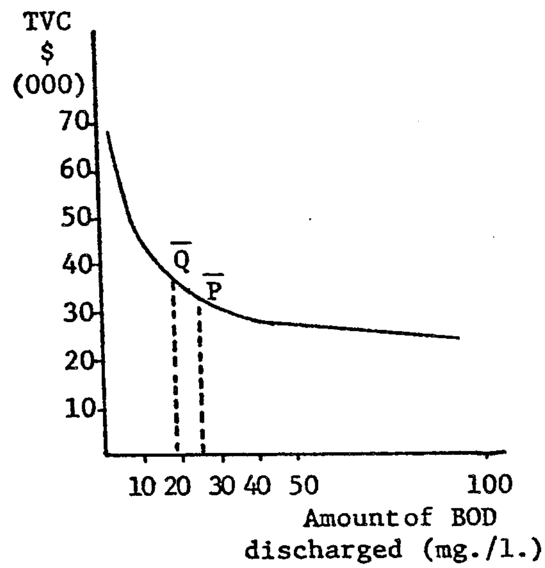
TOTAL SUBSIDY: 188 plants, $786,505 in 1980 dollars. Extending this estimate to include all 451 outstate plants the subsidy becomes $1,833,479 in 1980 dollars.

Third, within each group 69 percent of the total subsidy for activated sludge plants, 73 percent of the total subsidy for trickling filter plants and 95.5 percent of the total subsidy for stabilization ponds would go to municipalities which alreach comply with their BOD permit levels. The majority of the subsidy would, therefore, be given as a reward for achieving water quality at or below the designated standard. For example, \$231,958 of the \$335,047 for activated sludge plants would go to municipalities already meeting the water quality standard. The reason for this apparent lack of need for assistance can be illustrated by looking at the shape of the TVC curves and where the average plant operates on these curves. The curves in Figure 3 were estimated by substituting in the average values of each input price and varying the level of Q, the amount of BOD discharged. The points $\bar{Q}$ and $\bar{P}$ represent the position of the treatment plants, where $\bar{P}$ is the average permit level of BOD and $\bar{Q}$ is the average discharge level, for the given plant type. The activated sludge and trickling filter plants have the conventionally shaped cost curves. The ponds, which are not shown, would not have a continuous function. Cost would tend to run at some low level until BOD is discharged, then costs would rise. This leads to a number of points which tend to rise as BOD discharges increase. However, the individual plant would tend to have just two cost levels; one low when there is no discharge and another higher when BOD discharges occur.

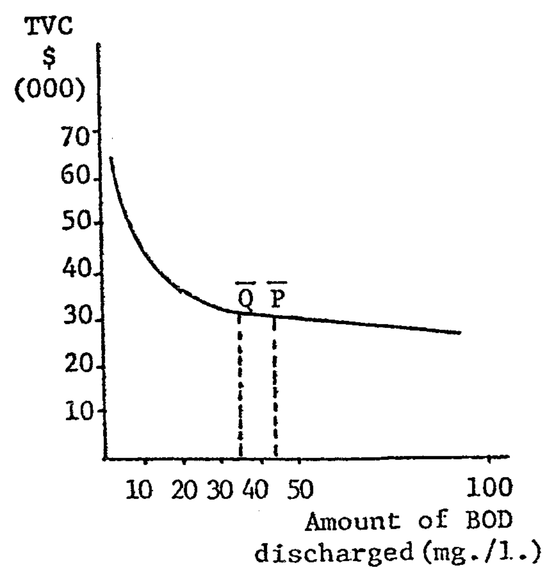
The curves for activated sludge and trickling filter have relatively flat portions, including the area where the average plant operates. The steepest part of the curves are where $\bar{Q}$ is less than 15 mg/l. As standards become tougher, holding input prices constant, the total variable costs for these plants will rise. Once the plants operate on this steep portion

FIGURE 3. Treatment Cost Curves

A. Activated Sludge



B. Trickling Filter



of the curve, it will become more costly to achieve higher water quality.

In the case of the ponds, the total subsidy is low because the cost of O&M for ponds is low. The average TVC for this sample of 70 plants was $15,840. This is due to the fact that most ponds do not use any chemicals; maintenance is low and electric power is not always required. The major expense is labor which often is only part time.

Subsidy Based on Physical Parameters

The second approach to estimating the O&M subsidy defines the cost functions in terms of physical parameters. To illustrate, Knapp (1978) uses the following parameters to estimate costs: BOD removed, average strength of influent as measured by suspended solids, the ratio of dry weather flow to total sewage flow, total sewage flow per capita of the population being served, age or number of years since the last major improvement and several additive and multiplicative combinations of these variables. Other studies of this nature include Michel (1970), Dames and Moore (1978), Thomass (1974), and Ganczarczyk (1974). In the past this has been the most popular approach to estimating O&M costs for treatment plants.

Knapp's analysis of 172 sewage plants located throughout Britain was admittedly short-run because capital cost was not included and an envelope curve was not fitted. The author's estimated cost relationship was only used to examine the operation of the treatment facilities. The resultant, L-shaped average cost curve implies significant economies of scale existed in the treatment facilities with daily flow 0-10 MGD.

As flow increased beyond this range the possibilities of economies of scale diminished.

Knapp points out that the omission of input prices and technology results in a misspecification of the cost relationship. He argues that his methodology is best used on cross-sectional data for a single year. Also, the plants of interest should be located in a relatively small and homogeneous geographic area.

The plants studied in Minnesota are rural in nature with size ranging from 0-6 MGD. There is also a fair degree of homogeneity among the sampled facilities. The sample population is only 113 plants. The majority of this smaller sample of plants is included in the 188 plants used to estimate O&M cost based on input prices. Again, the cost functions are estimated using the least squares procedure. The variables used to estimate total variable O&M costs (Y) are defined as follows:

X_1 = strength of effluent as measured by BOD (mg/l)

X_2 = strength of effluent as measured by total suspended solids (mg/l)

X_3 = flow (MGD)

X_4 = actual loading (lbs. BOD/day)

X_5 = degree of treatment, i.e. (influent-effluent) using BOD (mg/l)

X_6 = degree of treatment, i.e. (influent-effluent) using TSS (mg/l)

X_7 = percent of design loading (actual/design loading)

The total annual O&M cost figures are composed of labor, supplies and materials, projects contracted out, miscellaneous items and in some cases amortization. The cost data were obtained from an MPCA 1974 survey of municipal treatment plants. Labor cost includes wages, sick leave, and fringe benefits. Supplies and materials cost are made up of chemicals, office supplies and any other items needed in the every day operation of the plant. Projects contracted out consist of all payments for work done at the plant by non-city employees. Miscellaneous costs include items such as sludge disposal, grass cutting and week control. Amortization cost represents the cost of capital spread over the life of the treatment plant. For many plants this cost is now zero, but for those still paying, it is more correctly considered a part of the fixed capital costs. Its inclusion results in assuming that fixed cost affects the O&M of the plant. This is the opposite of the argument presented in the section on estimating total variable costs as a function of input prices. Amortization cost is retained in this case, because the method in which the data were collected makes it difficult to separate out.

The data for the independent variables were obtained from 1977 MPCA performance studies. The strength of the effluent as measured by BOD (X_1) and total suspended solids (X_2) is expected to be inversely related to the total O&M costs of activated sludge and trickling filter plants. As the amount of effluent being discharged increases, water quality falls. In other words the plant is treating less and, therefore, incurring less cost. In the case of stabilization ponds cost will probably rise as more effluent is discharged. This is because the pond holds the influent for a certain length of time during which O&M costs are low. At the time of discharge, however, more labor and in some cases electrical power are used, thereby, raising O&M costs as effluent is discharged.

The flow variable (X_3) measures the volume of wastewater entering the plant in millions of gallons per day and should be positively related to treatment cost. It is expected that as flow increases the amount of

BOD and suspended solids present to treat will also rise, thereby increasing the O&M cost.

The variable for actual loading (X_4) measures the amount of BOD per day, given a certain flow, entering the treatment plant. As actual loading increases more BOD will be present and treatment needs will rise. This should result in the O&M cost rising. Also, as the percent of design loading, (X_7) rises to 100 or above, total O&M costs are expected to rise. As the actual loading reaches the level for which the plant was designed, treatment costs should rise.

The variables representing the degree of treatment (X_5, X_6) are measured by subtracting the amount of effluent from the amount of influent. This is done using BOD and total suspended solids measured in milligrams per liter. Holding the influent constant, as the difference between influent and effluent increases, i.e. as the residual discharge approaches zero, cost is expected to rise. This is because the cost of removing that last few milligrams of BOD and TSS is the highest (see Figure 3).

Cost Functions Based on Physical Parameters

To begin the analysis the data are separated according to treatment technology. Within each subset different possible combinations of variables and functional form were screened to determine the best model based on the significance of the variables and the R^2 values. The resultant estimated cost relationships are as follows:

Activated Sludge[16/]

$$\text{Ln } Y = \underset{(31.21)^{**}}{10.00} + \underset{(8.17)^{**}}{.754}\, X_3 + \underset{(.79)}{.76 \times 10^{-3}}\, X_5 + \underset{(.59)}{.107 \times 10^{-2}}\, X_6 \qquad R^2 = .701$$

Trickling Filter

$$\sqrt{Y} = \underset{(15.98)^{**}}{278.45} - \underset{(-3.36)^{**}}{1.18}\, X_2 + \underset{(20.50)^{**}}{.11}\, X_4 - \underset{(-6.31)^{**}}{.49}\, X_5 + \underset{(.72)}{.12}\, X_7 \qquad R^2 = .907$$

Stabilization Pond

$$\sqrt{Y} = \underset{(5.05)^{**}}{123.86} - \underset{(-1.59)}{1.66}\, X_1 + \underset{(3.15)^{**}}{1.84}\, X_2 + \underset{(4.84)^{**}}{186.16}\, X_3 \qquad R^2 = .664$$

The majority of variables used to explain treatment costs are highly significant. Also, all of the significant independent variables, except one, have the correct signs associated with their coefficients. Only X_5 the variable representing the degree of treatment as measured by BOD, in the equation for trickling filter, has an unexpected negative sign and is significant. One reason for this could be its association with the other independent variables in the equation. The highest zero-order correlation (within the trickling filter equation) are those in which X_5 occurs.[17/] Finally, since the data used to estimate the equations comes from two different years, the result can only be considered as rough estimates of the actual relationships. At best, they can be used as a rough

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16/ The t-statistics are shown in parentheses.
*Statistically significant at the 95 percent level.
**Statistically significant at the 99 percent level.

17/ All equations were tested for multicollinearity using these correlation coefficients as well as other tests such as regression of the independent variables on one another and computation of the condition number. None of these tests, however, indicated harmful multicollinearity.

comparison with the costs estimated from input prices and BOD.

Estimated Subsidy (Physical Parameters)

In estimating the subsidy the same two situations exist as were present when the subsidy was estimated as a function of input prices. Some municipalities already were in compliance with their permit levels, while others were not. Again, both types of municipalities will receive a subsidy in order to avoid the possibility of the former increasing discharges above their permit so that they would be eligible for the subsidy.

To compute the subsidy the TVC calculated using the actual values of the independent variables is subtracted from the TVC estimated using values of the independent variables at the permit levels. To illustrate, the activated sludge plant in the city of Aitkin failed to comply with its permit in 1977. Using the actual values for X_3, X_5, and X_6 the total annual O&M costs (in 1980 dollars) are:

$$\text{Ln } Y = 10.00 + .754\ (.585) + .76 \times 10^{-3}\ (213) + .107 \times 10^{-2}\ (78)$$

$$\text{or } Y = \$43,758.$$

Substituting values based on the permit level of discharge for the actual values of X_5 and X_6 yield the following O&M cost:

$$\text{Ln } Y = 10.00 + .754\ (.585) + .76 \times 10^{-3}\ (243) + .107 \times 10^{-2}\ (100)$$

$$\text{or } Y = \$45,833.$$

The difference, \$45,833 - \$43,758 = \$2,075, is the subsidy that would be received by Aitkin if they lower their discharge to the legal permit level.

The trickling filter plant in Detroit Lakes provides an example of a plant that complied with its permit levels of discharge in 1977. The actual values of X_2, X_4, X_5 and X_7 are substituted in the estimated equation for trickling filter plants to obtain the following TVC:

$$\sqrt{Y} = 278.45 - 1.18\ (1) + .11\ (1807) - .49\ (247) + .12\ (42.4)$$

$$\text{or } Y = \$129{,}671.$$

Substituting values based on the permit level of discharge into variables X_2 and X_5 results in the following estimate of total O&M costs:

$$\sqrt{Y} = 278.45 - 1.18\ (30) + .11\ (1807) - .49\ (233) + .12\ (42.4)$$

$$\text{or } Y = \$115{,}074.$$

The difference, \$129,671 - \$115,074 = \$14,597, is the subsidy that would be given to Detroit Lakes as a reward for maintaining residual discharges below their permit level.

This procedure was followed for all three plant types. The results are presented in Table 3 according to size so that comparisons can be made with the other two types of subsidy. First, it is evident that performance in 1977 was not as good as that in the 1980 sample. Specifically in 1977, 82.4 percent of the activated sludge plants, 22.6 percent of the trickling filter plants and 61.5 percent of the stabilization ponds complied with their permit levels of discharge.

Second, this data set also supports the idea that it is the municipalities with the smaller plants, with design flow less than .5 MGD, which are more likely to violate their permits. Of the 77 plants within this size category, 53 percent do not comply with their permit levels. This is especially evident for small trickling filter plants where only 9 percent are in

TABLE 3

SUBSIDY BASED ON PHYSICAL PARAMETERS

SIZE MGD	NUMBER PLANTS	PERCENTAGE COMPLYING WITH PERMIT	TOTAL SUBSIDY	AVERAGE SUBSIDY PER PLANT
Activated Sludge:				
< .5	21	90.5%	$ 28,361	$ 1,351
.5 - 1.0	7	57.1	17,602	2,515
1.0 - 10.0	6	50.0	59,510	9,918
> 10.0	--	--	--	--
	34	82.4	$105,473	$ 3,102
Trickling Filter:				
< .5	34	9.0%	$171,607	$ 5,047
.5 - 1.0	10	50.0	98,911	9,891
1.0 - 10.0	9	44.0	60,711	6,746
> 10.0	--	--	--	--
	53	22.6	$331,229	$ 6,250
Stabilization Ponds:				
< .5	22	63.6%	$209,559	$ 9,525
.5 - 1.0	3	33.3	44,824	14,941
1.0 - 10.0	1	100.0	3,505	3,505
> 10.0	--	--	--	--
	26	61.5	$257,888	$ 9,919

TOTAL SUBSIDY: For 113 plants, $694,590 in 1979 dollars and $777,941 in 1980 dollars. Extending this to include all 451 outstate plants the subsidy becomes $3,193,700 in 1980 dollars.

compliance. However, the small activated sludge plants performed as well as or better than any other size category in the data set.

Third, within each plant type, 62 percent of the total subsidy for activated sludge plants, 28 percent of the total subsidy for trickling filter plants and 59 percent of the total subsidy for stabilization ponds would have gone to municipalities already in compliance with their permit levels of discharge. The majority of the subsidy serves its intended purpose of providing an incentive to reduce residual discharges to the permit level. This is the opposite of the situation in 1980, where most of the subsidy would have been awarded to municipalities already complying with their permits. This helps to explain why the final estimates of the O&M subsidy for all 451 outstate plants is almost twice as much as the estimate based on input prices (1980). In 1977 treatment facilities were further from their permit levels than in 1980.

Subsidy Based on the State Proposal

The third approach to estimating the O&M subsidy is based on the New York State Assistance Program as applied to Minnesota Plants. This proposal differs from the previous approaches in that aid is not given based directly on plant performance but according to size.[18/] Tables 4 and 5 illustrate Minnesota's subsidy proposal based on the 1980 data

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[18/] The state proposal would maintain conditions such as: (1) a qualified operator in charge, (2) a sewage collection system which does not discharge or bypass untreated waste under conditions of maximum dry weather flow, and (3) adherence to the state or federal pollution discharge elimination system permit which sets limits on the pollutants discharged in the effluent from the plant. For an example of how such guidelines are implemented in an O&M assistance program see New York State Department of Environmental Conservation, State Aid for Operating Sewage Treatment Plants, Program Audit, Albany, New York, April 1979.

TABLE 4

SUBSIDY BASED ON 1980 DATA SET AND PLANT SIZE

SIZE MGD	NUMBER PLANTS	PERCENTAGE SUBSIDY	TOTAL O&M	TOTAL SUBSIDY	AVERAGE SUBSIDY PER PLANT
Activated Sludge:					
< .5	42	50%	$1,649,613	$ 824,807	$ 19,638
.5-1.0	4	40	358,612	143,445	35,861
1.0-10.0	6	30	874,541	262,362	43,727
> 10.0	2	25	1,808,141	452,035	226,018
	54		$4,690,907	$1,682,649	$ 31,160
Trickling Filter:					
< .5	49	50%	$1,475,164	$ 737,582	$ 15,053
.5-1.0	6	40	318,120	127,248	21,208
1.0-10.0	9	30	1,454,263	436,279	48,475
> 10.0	0	25	--	--	--
	64		$3,247,547	$1,301,109	$ 20,330
Stabilization Pond:					
< .5	65	50%	$ 801,538	$ 400,769	$ 6,166
.5-1.0	3	40	108,692	43,477	14,492
1.0-10.0	2	30	184,692	55,408	27,704
> 10.0	-	25	--	--	--
	70		$1,094,922	$ 499,654	$ 7,138

TOTAL SUBSIDY: $3,483,412 for 188 plants. Extended to the 451 outstate plants this becomes $7,768,392 (1980 dollars).

TABLE 5

SUBSIDY BASED ON 1974 DATA SET AND PLANT SIZE

SIZE MGD	NUMBER PLANTS	SUBSIDY	TOTAL O&M	TOTAL SUBSIDY	AVERAGE SUBSIDY PER PLANT
Activated Sludge:					
< .5	21	50%	$ 810,490	$ 405,245	$ 19,297
.5-1.0	7	40	407,682	163,073	23,296
1.0-10.0	6	30	3,443,220	1,032,966	172,161
> 10.0	-	25	--	--	--
	34		$4,661,392	$1,601,284	$ 47,096
Trickling Filter:					
< .5	34	50%	$1,354,331	$ 677,166	$ 19,917
.5-1.0	10	40	647,363	258,945	25,895
1.0-10.0	9	30	2,566,934	770,080	85,564
> 10.0	-	25	--	--	--
	53		$4,568,628	$1,706,191	$ 32,192
Stabilization Ponds:					
< .5	22	50%	$ 706,677	$ 353,339	$ 16,061
.5-1.0	3	40	293,839	117,536	39,179
1.0-10.0	1	30	49,963	14,989	14,989
> 10.0	-	25	--	--	--
	26		$1,050,479	$ 485,864	$ 18,687

TOTAL SUBSIDY: $3,793,339 for 113 plants. Extended to the 451 outstate plants, this becomes $15,112,552 (1980 dollars).

set and the 1974 data set, respectively. The highest subsidy rate, 50 percent of O&M, is given to municipalities with the small plants and the lowest subsidy rate, 25 percent, goes to those with the largest plants.

In both cases, the state proposal results in a larger subsidy for O&M than the two alternative approaches. The main problem is that too much money is allocated to municipalities with the larger plants, i.e. those with design flows greater than or equal to 5 MGD. This is contrary to what was found as the problem plants. The smaller trickling filter plants were the ones most likely to operate with discharges in excess of their permit levels. The state proposal also allocates the majority of aid to municipalities which in 1980 met their permit levels of BOD discharge without the incentive of a subsidy. To partially correct this situation, the subsidy by plant capacity could be reduced. For example, the allocations could be 50 percent for less than .10 MGD; 40 percent for .10-.50 MGD; 30 percent for .50-1.0 MGD; 20 percent for 1.0-3.0 MGD and 10 percent for greater than 3.0 MGD. This breakdown results in a subsidy of $5,725,600 for the 451 outstate plants based on the 1980 data set. This is a savings of $2 million over the subsidy shown in Table 4. The subsidy based on the TVC of meeting permit levels could also be reduced by paying only part of the extra cost. For example, only half the cost of maintaining discharges below the permit levels could be paid.

Based on a questionnaire answered by 127 plant operators, an MPCA study (1978) found that the percent subsidy by plant size shown in Tables 4 and 5 resulted in a relative equalization of the annual net cost per capita. Their calculations were based on an average cost per facility of $57,800 and the three facility types were not differentiated.[19/] The estimate of the O&M subsidy based on 1974 data is twice that of the 1980 estimate mainly because plant performance was much worse, especially for trickling filter plants and stabilization ponds. The total subsidies are calculated assuming that all plants obtain a subsidy.

Summary of Quantitative Analysis

The three methods of estimating the subsidy resulted in estimates based on two sample populations. Assuming that these samples are representative of the total population, the results can be extended to include all of the outstate facilities. The final estimates of the subsidy are based on 194 ponds, 107 activated sludge plants and 150 trickling filter plants. Stated in 1980 dollars these estimates are as follows:

I.	Based on Input Prices	$1,833,479
II.	Based on Physical Parameters	3,193,700
III.	State Proposal Based on Plant Size	
	a. Using 1980 Data Set	7,768,392
	b. Using 1974 Data Set	15,112,522

The State proposal yields the largest estimates for the subsidy. The main weakness of this approach, besides cost, is its failure to account for characteristics of the actual treatment processes, such as BOD removed, flow, technology used, and the strength of the influent. Also, the breakdown of plants by size is arbitrary, although it can be

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19/ These were the initial findings of an MPCA study done in 1976 and reported in a 1978 MPCA memorandum.

adjusted so that per capita costs of treatment become relatively equal. The state proposal has the advantage of being easy to implement and recent studies of New York's program show it as a successful means of improving water quality.[20/]

The approach based totally on physical parameters resulted in an intermediate estimate of the subsidy. The physical parameters approach has the advantage of being able to examine two measures of water quality, BOD and TSS. Also, the data requirements are easier to meet. As previously discussed, the main weaknesses are that cost is calculated as a function of physical measures of effluent and influent and that the data used is from two different years. The cost curves based on input prices are estimated as a function of input prices and output (BOD). However, the necessary conditions which define a cost curve did not all hold for the three estimated cost curves. Cost curves based on input prices also have the most difficult data requirements. Further, the approach ignores physical parameters (except for BOD discharged), which this analysis and many others have shown to be important variables in explaining the variability in TVC. It can also be argued that the assumption of perfect competition and the "firm" behaving as a cost minimizer does not adequately describe the real situation.

Although a performance trend cannot be estimated with just two years' data, the estimates of the O&M subsidy seem to suggest one. Plant performance in terms of meeting permit levels is better in 1980 than in 1977 and the total subsidy falls from $3,193,700 to $1,833,349. This relation-

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[20/] New York State Department of Environmental Conservation, pp. 14-38.

ship also shows up in the estimates based on the state proposal. As performance improved, the estimate of O&M assistance fell, from $15,112,522 to $7,768,392.

The great majority of plants were, on the average, meeting their discharge permit levels in 1980. Consequently, the need for a subsidy has declined and the majority of funds would go to plants already meeting their permit levels.

SUMMARY AND CONCLUSION

Summary

The analysis of the need for O&M assistance has been done in a qualitative and quantitative fashion. Qualitatively, factors limiting plant performance such as staffing deficiencies, inadequate laboratory testing, and training deficiencies might be rectified by an O&M subsidy. However, planning and construction delays, design, equipment and material deficiencies and industrial waste problems will not be corrected by an O&M subsidy.

Based on the 1980 data, 83 percent of the sampled plants complied with their permit levels of discharge. Improved operator training, adequate maintenance and federal and state regulations seem to have overcome many of these performance limiting factors. The MPCA has, at the present time, a good program for operator training and certification. As this educational process continues, an increasing number of operators will be better prepared to utilize their capabilities to operate plants efficiently.

The quantitative analysis raised further questions concerning the O&M subsidy. Although the monthly average discharge for the year was used in the analysis, there may be significant differences in discharge levels during the year. Also, the analysis was done using BOD as the measure of water quality. Plant performance may be worse for other measures such as TSS or chloroform. This is especially true for stabilization ponds which tend to remove more BOD than TSS or chloroform. On the whole, however, it appears that a subsidy to increase water quality would have been given as a reward to those already below their permit levels. Because they achieved high levels (less than 25 mg/l BOD discharged) of water quality without a subsidy it appears this incentive was not needed.

The performance of 17 percent in non-compliance needs to be examined in more detail by MPCA officials. There may have been extenuating circumstances, such as expansion of the plant, preparing to construct a new plant, or the training of a new operator, which resulted in their non-compliance with the effluent standard.

The analysis based on physical parameters builds a better case for a subsidy than does the analysis based on input prices. In this data set, 63 percent of the 113 plants operated within their permit levels. The majority of the 37 percent that did not, were trickling filter plants, This data described discharges in 1977, while the data based on input prices used discharges from 1980. Although the two samples were not identical, both contained many of the same plants. Even so, the smaller trickling filter plants and stabilization ponds appear to have improved their performance.

Of the incentive systems examined, a subsidy based on plant size is the largest. For example, the results from the 1980 data indicate that the average subsidy based on input prices would amount to 5-1/2 percent of the total annual O&M cost of an average trickling filter plant, 7 percent of an average activated sludge and 23-1/2 percent of an average stabilization pond. In comparison, the proposal based on plant size would award subsidies that amount to 38 percent of the total annual O&M cost of an average trickling filter plant, 36 percent of an average activated sludge plant and 45 percent of an average stabilization pond. The low percentages of the method based on input prices may indicate that the subsidy is not large enough to provide much of an incentive to improve water quality.

An additional problem may exist with implementing a subsidy program based on treatment costs. The governing agency must decide if the subsidy will be allowed to vary monthly, quarterly or yearly. As levels of discharge vary so might the level of the subsidy. For example, a plant may discharge 50 mg/l BOD in June with a permit of 25 mg/l BOD but discharge only 20 mg/l in January. The municipality would be eligible for a subsidy in one month but not the other. The administrative difficulties which these alternatives impose may be their biggest disadvantage when compared to proposal based on plant size.

Also basing a subsidy on estimated cost equations may be difficult to defend. The cost equations in this study represent the years 1977 and 1980. In addition, the estimated cost equations are not significant enough to provide a sound basis for setting subsidy level. Recomputing these equations on an annual basis would be time consuming. It would also increase the time between a community's application for a subsidy and its receipt of the subsidy.

In general, it must be assured that the communities receiving a subsidy use the funds to deal with problems in their treatment plants. The subsidy is an incentive, and reward for improving water quality. The increased costs incurred in achieving a higher level of water quality should be planned for in the local budget. A subsidy received during or at the end of the year should be used in the following year's budget for the treatment plant. The subsidy should not be allowed to go into a general municipal fund as this would defeat the idea of an incentive to improve water quality. The failure of the New York program in New York City is evidence of the ineffectiveness of allowing the subsidy to go into a general fund.

Limitations

There are six limitations which must be recognized in this study. First, the statistical analyses are based on cross-sectional data. The two approaches examined the discharge levels as it was in 1977 and 1980. Comparisons between years and methods are interesting, but no significant trends can be identified. A time series analysis is needed and would strengthen the study.

Second, BOD was used as the primary measure of treatment in the cost functions based on input prices and output (BOD). There are other indicators of water quality such as TSS which may be more appropriate for a given technology. Another possible output would have been the actual flow. However, due to the nature of the problem and the need to have one indicator of water quality, flow was not used.

Third, the data used to estimate cost functions based on physical parameters was from two different years. The discharge levels were from 1977 while the costs came from 1974. It is highly possible that conditions in 1974 and 1977 are so different that the cost relationships are of little significance. Clearly subsidies would have to be based on new estimates using current data.

Fourth, many independent variables were omitted from the analyses. Evidence of this is the relatively low R^2 in the method using input prices. Other potential variables are: debt charges, revenue contributions to capital, variations in the rate of flow, age of capital, characteristics of capital stock, years since last capital improvement, climate and population. Sacrifices in the number of variables were necessary in order to develop a workable and understandable model.

Fifth, the use of a survey is always limited by the accuracy of its answers. If communities believed they would be eligible for an O&M subsidy, if need could be demonstrated, then perhaps some answers would be biased. Because of the unofficial nature of this study and the fact that answers were scrutinized and checked it is believed that the survey results are reliable.

Finally, there is the shortcoming inherent in all short-run analyses. Many feel that without the inclusion of capital costs long-run planning cannot be accomplished. It has been argued that the long-run planning has fixed the short-run situation as far as existing municipal treatment plants are concerned. The impact of biases in the construction grant program have been discussed as have their relationship to the problems of the short-run. The separation of capital and O&M costs is justified because the problem examined is short-run.

Conclusion

Those plants operating over permit levels need to be evaluated so that the specific reasons for the excessive discharges can be determined and corrected. The results may call for changes in the treatment process, capital improvements in the facility, increased operator training, etc. Conducting these types of evaluations and corrective actions would be less expensive than a multi-million dollar O&M subsidy program. A potential source of funding would be for the state to divert money from state construction grants to a special technical assistance program designed to achieve increased efficiency in O&M. This would involve field inspection by the MPCA. These inspectors would work closely with plant operators so that both would learn what the problems are and how they can be dealt with.

An alternative longer term solution would be to alter the Federal cost sharing rules to ensure that the biases against certain techniques and cost types are eliminated or reduced. This solution is discussed in the Appendix which follows.

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APPENDIX

COST SHARING POLICY ALTERNATIVES

Marshall and Ruegg (1975) offer several alternative methods of cost sharing all of which attempt to reduce or eliminate the bias toward certain techniques and types of cost. These alternatives provide long-run solutions to the resource allocation problem in that future facilities would be affected. The first alternative is to offer equal percentage cost sharing of all categories of cost for all treatment technologies. This would eliminate any bias toward capital cost, which presently is the only type of cost eligible for cost sharing. Local communities would be encouraged to choose least cost technologies, which are consistent with the national interest. The only problem which may arise is making all costs eligible for federal cost sharing. This may be contrary to the widely held belief that costs such as O&M are strictly local responsibility. Also, these cases occur over time and mean a long term commitment of federal funds.

The second alternative uses flexible cost sharing rules for a given type of cost but varies them among techniques so that the effective total cost shares are equal. As the composition of cost among technologies changes, so does the percentage cost share for the one eligible cost category. The result is that local communities end up paying the same percentage of total costs for all technologies. This has the same effect as the first alternative, but avoids making cost types, other than capital, eligible for federal funding.

The third alternative is to constrain the allowable federal share for all techniques by some arbitrary percentage. This rule would greatly reduce or eliminate biases among techniques and does not require all cost categories to be eligible for funding. For example, projects could still receive 75 percent funding for capital and 0 percent for O&M costs but the total federal share could be limited to 25 percent. O&M intensive techniques would be as appealing and cost minimizing as capital intensive techniques. This rule has the advantage of being able to adjust the federal share so that the number of projects receiving federal funding can rise for a given federal budget.

In examining the impacts of these alternatives Marshall and Ruegg (1975) assume that they had been in effect from the beginning of the construction grants program. They assume the same number of projects under each cost sharing rule. Historically, the federal share of the total $20.6 billion spent on waste treatment plants is $4.9 billion or 24 percent. The current rule of funding, 75 percent of capital costs, results in a federal cost share (of total costs) of 49 percent, while the nonfederal share is 51 percent. Since there is also state aid for capital costs, communities end up paying less than 51 percent of the total cost.

Applying equal percentage cost shares to all types of costs for all techniques results in the same federal cost share (49 percent) as the existing rules. The difference is that biases towards capital cost are eliminated without any additional cost to the federal government. Had this rule been in place less costly projects would have been built thereby reducing the costs to all parties of achieving desired levels of abatement.

Because of a lack of data the flexible cost sharing rules necessary to provide equal total cost shares among technologies was omitted. The authors contend that this rule would also have lowered the total cost of achieving a given level of abatement. Like the equal share alternative, this rule would have induced the construction of more efficient technologies.

The effects of a constraint on the total federal share was illustrated using 37 percent as the upper limit. This is the average of the historical 24 percent federal share and the share, 49 percent, implied by the current law. The federal share of total cost depends on the ratio of capital to total costs. As this ratio rises above the level where the constraint is effective, the federal share becomes fixed. Historically, if the desired level of abatement had remained at pre-1972 levels, this rule would have resulted in less expenditures for all parties. Since the federal share is constrained, communities would have had to pay more and some projects would not have been so appealing. These observations do not account for the fact that state subsidies now exist. The state subsidies reduce the effect of constraining the federal cost share.

In conclusion, sharing costs in all cost categories across all techniques would result in the equal percentage cost shares needed to eliminate the biases created by the existing system. If this is not possible then the other two alternatives discussed above could be used. If one of these approaches had been implemented at the outset of the construction program there would be no need of an O&M subsidy. In rural areas, more onsite treatment and disposal systems would have been built, because they would be subsidized in the same fashion as an activated sludge plant. To avoid future misallocations of resources the existing cost sharing rules need to be altered.