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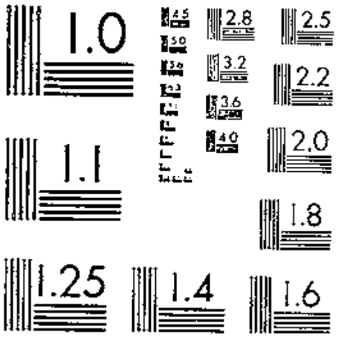

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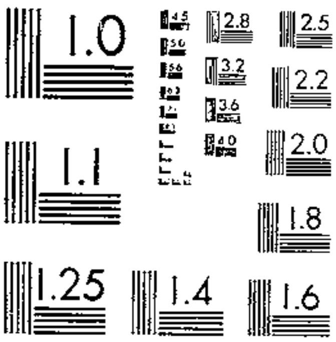

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JOINT MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT IN RURAL COMMUNITIES:

Simulation Analysis with Poultry Processing Plants

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U.S. Department of Agriculture
Economics, Statistics, and Cooperatives Service

Technical Bulletin No. 1615

JOINT MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT IN RURAL COMMUNITIES: Simulation Analysis with Poultry Processing Plants, by Daniel Rossi, C. Edwin Young, and Donald J. Epp. Natural Resource Economics Division; Economics, Statistics, and Cooperatives Service; U.S. Department of Agriculture. Technical Bulletin No. 1615.

ABSTRACT

Joint wastewater treatment decisions are simulated for poultry processing plants and rural communities. Cost impacts from variations in wastewater influent quantity and quality are isolated. Rural communities generally benefit from joint treatment situations since the effects of economies of size override cost increases associated with treating more concentrated wastes. If poultry processing plant waste discharges are reduced after construction of joint treatment facilities, communities may be forced to incur substantially higher treatment costs. Federal construction subsidies alter joint treatment decisions in two ways: they introduce a bias toward capital-intensive treatment technologies, and they encourage industrial participation because of the presence of interest-free capital.

Keywords: Wastewater, Joint treatment, Simulation, Industrial wastes, Rural communities, Subsidies, Economies of size, Costs.

Washington, D.C. 20250

March 1980

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SUMMARY

The impact of industrial participation on the costs of municipal wastewater treatment in small communities is examined using data from the poultry processing industry and engineering models to simulate the operation of wastewater treatment facilities.

Economies of size associated with wastewater treatment facilities serving small communities result in lower average total costs for communities using activated sludge and lagoon secondary treatment systems to handle residential and poultry processing wastes jointly. Trickling filter costs are higher due to a sensitivity to the high organic loadings resulting from the participation of poultry processing plants. The relative size of the community and the processing plant in part determine the magnitude of the cost impacts.

There are additional cost savings from joint treatment when advanced wastewater treatment techniques such as inplant tertiary and land treatment systems are required, since economies of size are greater for these types of systems than for secondary treatment. The Federal construction subsidy program established under P.L. 92-500 results in substantially reduced local treatment costs, but the general relationships between treatment costs and factors such as community size, treatment technology, and industrial participation do not change appreciably.

The construction subsidies provide a bias towards capital-intensive systems, but this bias is not sufficient to change the rankings, in terms of costs, of the different types of treatment systems. It does, however, lead to a subtle type of inefficiency when the least-cost design of a specific system changes.

There also is a direct economic incentive for communities to seek long-term agreements with poultry processing plants to participate in joint treatment facilities; however, this incentive is substantially reduced when the government subsidizes construction costs.

A plant's utilization of municipal treatment services is related to the costs of alternative methods of waste disposal available to the plant. When the costs of public treatment to the plant are equal to the average costs of joint treatment, the plant will always select joint treatment if similar systems are designed for both public and private treatment. This is attributable to such factors as the economies of size in wastewater treatment, the less stringent treatment requirements for public facilities, and the lower cost of capital facing the municipality. If different types of treatment systems are planned, the plant's decision depends on the types of treatment designed for each facility, the size of the poultry processing plant, and the size of the residential population served by the municipal facility.

The Federal construction subsidy program affects the costs of municipal treatment to the plant and, therefore, the level of poultry processing plant participation in joint treatment systems. The cost of public treatment to the plant is lower after the introduction of the subsidy program even when the plant is required to pay its share of the remaining capital costs in addition to a capital cost recovery fee plus the plant's proportionate share of operating and maintenance costs. This is so because the capital cost recovery fee does not include a charge for interest.

Joint Municipal and Industrial Wastewater Treatment in Rural Communities:

Simulation Analysis with Poultry Processing Plants

*Daniel Rossi, C. Edwin Young, and Donald J. Epp**

INTRODUCTION

Two major pieces of legislation establish as a national goal the elimination of the discharge of pollutants into the navigable waters of the United States: the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) and the Clean Water Act of 1977 (P.L. 95-217). More specifically, they provide for the development of definite guidelines for effluent discharge from all point sources, public and private. They also provide for Federal financial assistance in the form of capital subsidies to communities attempting to achieve these guidelines. Many communities are designing upgraded or new wastewater treatment facilities in response to the requirements established in P.L. 92-500. The latest Environmental Protection Agency (EPA) "needs survey" estimates the cost for construction of publicly-owned wastewater treatment facilities to serve 1990 populations to be $95.9 billion (28). 1/ Of this total, nearly $13 billion are required for construction of secondary treatment facilities, $21.3 billion are required for facilities providing more stringent treatment, and the remaining $61.6 billion are required for conveyance and control of pollution from combined sewer overflows.

The magnitude of the public investment required in wastewater treatment during the next few years makes it imperative that relevant decisionmakers have a thorough understanding of the issues involved. One particular issue is industrial participation in the municipal wastewater treatment system. Industrial discharges often significantly alter the total flow and concentrations of various wastewater constituents, such as biochemical oxygen demand (BOD), suspended solids, and heavy metals, to be treated by municipal treatment facilities. 2/ These factors are important in determining the size and type of treatment processes required to meet the increasingly stringent standards being imposed on communities, so specific attention must be paid to the expected level of industrial participation during the planning and design stages of the new construction. This is particularly true for smaller communities where industrial contributions often represent a significant proportion of the total wastewater load to be treated.

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1/ Underscored numbers in parentheses refer to literature references listed at the end of this report.

2/ Appendix A contains a partial glossary of terms and abbreviations of a technical nature used in this report.

This study examines the implications of the joint treatment of domestic and industrial wastewater, with emphasis on small communities. A theoretical model is utilized to evaluate the impact of industrial participation on municipal wastewater treatment costs. A second model is used to describe industrial use of municipal wastewater treatment services; that is, industrial demand for municipal treatment services. An integration of these models provides a framework within which to identify the conditions for cost-effective joint treatment and to examine the effects of various governmental policies, including capital subsidies, industrial cost recovery requirements, and pricing strategies. Data from the poultry processing industry are used to examine the above relationships and to simulate the effect of the various governmental policies on cost-effective solutions.

Significant cost savings are available to rural communities as the result of joint treatment agreements with the poultry processing industry. In fact, the potential cost savings from such agreements may be larger than predicted here. It is assumed that the poultry processing plants are not required to perform any pretreatment of their wastewater other than preliminary screening for feathers and large solids. Establishment of pretreatment requirements may result in a smaller quality effect and, therefore, a larger net decrease in per unit costs.

There also are significant cost savings available to poultry processing plants from joint treatment arrangements. These savings may be somewhat overstated, since the cost estimates for private inplant removal do not include alternatives to end-of-pipe treatment such as partial treatment. The magnitudes of the cost savings available to firms, as found in this study, are large enough to warrant at least recognition of the potential incentives that exist for firms to enter into joint treatment arrangements.

The analysis presented in this study suggests the potential for mutually agreeable joint treatment arrangements between rural communities and poultry processing plants located in those communities. Barring prohibitory transaction costs and regulatory constraints, the cost savings affordable through joint treatment provide economic incentives, in many cases, for both parties to enter into such arrangements. It is important, then, that local decisionmakers recognize the existence and interdependence of these incentives during the planning of new or expanded wastewater treatment facilities, and during other plans for future community development involving industrialization. In addition, policymakers at other levels of government should also recognize the potential for these incentives. For example, it is shown that the Federal construction subsidy program not only has an impact on communities through direct effects on local treatment costs, but also an indirect effect through the level of industrial participation. The subsidy program, as it is currently administered, generally increases the attractiveness of joint treatment to the plant. The literature also suggests, though, that it increases the attractiveness of joint treatment to communities by allowing them to retain a portion of the industrial cost recovery fees.

Care should be exercised in using the results of this analysis. Simulation studies such as this are useful in making relative comparisons and observing general relationships. Their results should not be interpreted to represent any particular community or poultry processing plant due to site specific conditions and costs. In addition, care has to be exercised in generalizing the results of this analysis to other industries. Their wastewater streams may differ considerably in flows and concentrations of pollutants and should, therefore, be analyzed separately. For example, the metal-plating industry, which also often locates in small communities, may introduce large quantities of heavy metals into municipal treatment facilities and, thereby, may preclude certain treatment and disposal techniques.

CONCEPTUAL FRAMEWORK

Planning for the joint treatment of domestic and industrial wastewater is a crucial element in the design of cost-effective treatment systems. The impact of joint treatment on the various participants and their corresponding responses will be important in determining the type and size of facilities required.

The municipality is required to provide joint treatment when certain conditions are met, but it has considerable flexibility in making use of such policy instruments as pricing strategies and pretreatment requirements to encourage or discourage joint treatment. The municipality will compare the additional benefits and costs of joint treatment in order to determine its policies.

EPA describes several benefits a municipality may anticipate from joint treatment (30, pp. B15-B16). One such benefit is the potential economies of size associated with small-scale treatment facilities which serve rural communities. The increased flow from industrial participation, ceteris paribus, is expected to result in lower average treatment costs. The increased flow may also result in a reduced peak-to-average flow ratio, thereby increasing capacity utilization. Treatment of combined wastes also allows the use of nutrients available in domestic wastes for biological treatment of industrial wastes that may be nutrient deficient.

Finally, the structure of the Federal construction subsidy program and the associated industrial cost recovery requirements provide incentives for municipalities to treat industrial wastes. This program requires the industry using municipal wastewater treatment services to pay back the proportion of the subsidized construction costs that are attributable to the treatment of the industry's wastewaters. The local community is allowed to retain 50 percent of the construction costs paid by the industrial users (of which 80 percent will be used for future construction costs and 20 percent may be used at the discretion of the municipality), so this system provides a direct financial incentive for municipalities to encourage industrial participation in wastewater treatment facilities. Marshall and Ruegg describe this incentive in more detail (8).

Inclusion of industrial wastes in municipal wastewater treatment systems can, however, lead to additional system costs. Many industrial wastewaters, while compatible with common treatment processes, are more highly concentrated, in terms of constituents such as BOD and suspended solids, than normal domestic sewage. The inclusion of these wastes, therefore, may require longer detention times and/or equipment with larger capacities, resulting in higher per unit treatment costs.

Industrial wastes often contain high levels of pollutants, such as heavy metals, grease, cyanide, and many organic compounds, which are incompatible with certain biological treatment technologies (27). The efficiency of biological processes may be lowered with the presence of certain pollutants, thereby creating the potential for increased pass-through of pollutants and possible violation of the municipality's National Pollutant Discharge Elimination System (NPDES) permit for direct discharge 3/.

Sufficient levels of some pollutants may even cause a complete breakdown. To prevent such a breakdown, the treatment facility may have to substitute higher cost treatment alternatives or require additional treatment processes not otherwise necessary for treatment of the municipal wastes, and therefore, not subject to Federal

3/ In cases where the effluent is used as irrigation water, inclusion of incompatible industrial wastes may lower the quality and, therefore, the value of the effluent.

subsidies In addition, industrial pollutants are likely to become concentrated in the wastew ter sludges. This may lower the quality of resultant sludges, making them unsuitable for certain disposal methods and possibly increasing disposal costs. Finally, incompatible wastes from industrial sources may simply pass through the treatment plant without affecting its operations and associated costs, but may cause the plant to violate its NPDES permit with respect to the corresponding pollutants.

Municipal wastewater treatment authorities have several policy instruments available to influence the level of industrial participation, including user charges and surcharges. The former refer to charges placed on any of the characteristics, such as flow, temperature, pH, or concentrations of various constituents, including BOD, suspended solids, nitrogen, phosphorous, and heavy metals, of the wastewater contributed by a user of the treatment facilities. Federal law requires the recipients of Federal construction grants to establish a system of charges such that each recipient of the waste treatment services pays a proportionate share of operating and maintenance costs, but the actual implementation and level of such charges are, at least partially, at the discretion of the treatment authority. Surcharges, on the other hand, refer to charges that apply to wastewater constituents in excess of a prespecified normal concentration.

The industrial response to sewer charges is anticipated to be a reduction in the amount of wastewater released into the sewer system (5). Firms may utilize a number of methods to accomplish this reduction, including changes in the production processes, improved housekeeping, or private inplant treatment. Two empirical studies found that firms will respond to surcharges by reducing the quantity of wastes that they contribute to municipal wastewater treatment systems (2, 3).

Direct regulation in the form of pretreatment requirements represents an alternative policy instrument for the municipal authority. Pretreatment requirements refer to standards for wastewater from point sources that must be met as a condition for discharge to the municipal system. Industrial responses to pretreatment requirements and user charges are very similar. Firms may either pretreat wastes to the required levels, change manufacturing processes to lower pollutants in their waste stream, or disconnect from the municipal system by seeking their own discharge permit, relocating, or going out of business (27).

Municipal authorities have some influence on the level of industrial participation in joint wastewater treatment systems, but other factors also have an effect. Industry must compare potential benefits and costs of participation. As for the former, municipal treatment costs are potentially lower than private inplant treatment costs for several reasons (27). There are economies of size in wastewater treatment services which may permit lower per unit costs for joint treatment. Through joint treatment, an industry avoids the extra costs of obtaining its own NPDES permit for direct discharge. Another benefit stems from the fact that municipal treatment standards are generally less stringent than those for private discharges (26). Finally, even though industrial dischargers are required to pay their proportionate share of federally subsidized construction costs, they may take up to 30 years to do so and are not required to pay interest charges. This policy results in an additional subsidy to industry, since the discounted present value of the industrial cost recovery fees is less that the original subsidized construction costs (7).

Costs in addition to the direct costs of joint treatment, such as applicable user charges, surcharges, and industrial cost recovery fees, may be incurred if pretreatment standards are enforced. Economies of size associated with wastewater treatment processes may cause the need for individual pretreatment facilities to substantially increase the industry's share of the cost of joint treatment. Another cost resulting from joint treatment arrangements is nonpecuniary in nature. Plant managers not only directly sacrifice part of their control over plant operations when industry uses municipal treatment services rather than providing their own, but they also partially sacrifice flexibility in future operational decisions due to constraints stemming from formal agreements with the municipal treatment facility.

Municipal Wastewater Treatment Services

The municipal wastewater treatment authority combines various technologies and inputs to produce wastewater treatment services for its customers. These services include collecting, treating, and disposing of wastewaters from residential, commercial, and industrial point sources. The primary focus of this study is on one element of these services--treatment. Treatment refers to the process by which various components of the wastewater stream are removed and/or altered such that the remaining products (effluent and sludge) may be disposed of within relevant economic, legal, and environmental constraints.

The output of wastewater treatment, then, is not a tangible good. It is a service--the transformation of wastewater streams from various sources and with various characteristics into products which can be safely disposed of or utilized. As such, it can be considered to have a quantity and a quality dimension. The quantity dimension refers to the volume of wastewater flowing through the treatment facility during a specified period of time; that is, a rate of flow. The quality dimension refers to the level of treatment performed, as measured by the removal of the biological or chemical constituents, such as BOD, suspended solids, nitrogen, phosphorous, and heavy metals, from the wastewater stream.

These two dimensions of output are jointly determined, but not necessarily in fixed proportions. It is possible to trade off a higher level of treatment, holding factor usage constant, by decreasing the rate of flow of wastewater through the treatment facility, and vice versa.

Following (34), a generalized production function for wastewater treatment can be written with a quality variable on the right hand side in order to parcel out the effects of quality variation on the dependent variable:

$$F = f(R, I, E, T) \tag{1}$$

where:

F = flow of wastewater through the treatment plant,

R = a vector representing the removal of the biological and chemical constituents,

I = a vector of factor inputs (land, labor, capital, chemicals),

E = a vector of environmental factors affecting input requirements but not under the control of the decisionmaker (population density, weather, legal constraints), and

T = state of technology.

Several adjustments can be made to equation (1). First, the quality variable as measured by the removal of biological and chemical constituents can be considered to be dependent upon the characteristics of the wastewater influent stream and desired effluent characteristics. The former may be represented as a series of vectors (Q_i) of quantities of wastewater constituents per unit of influent from each industrial source (i) and a vector (Q_D) of the quantities of constituents per unit of influent from domestic sources. The effluent characteristics can be represented as a vector (Q_E) of the quantities of wastewater constituents per unit of effluent remaining after treatment.

Second, in the process of providing wastewater treatment services, the municipal treatment authority produces two products: effluent and sludge. In some situations, these products are sold directly as irrigation water and soil conditioners, respectively. In other situations, they may be applied to land either as a method of treatment or disposal and the corresponding byproducts (that is, crops or timber) may be sold. Thus, an additional term representing a vector of salable byproducts (B) can be included in the municipal wastewater treatment production function.

Making the appropriate substitutions and adjustments to equation (1), Then, the result is as follows:

$$F = g(Q_i, Q_D, Q_E, B, I, E, T) \qquad (2)$$

To develop a cost function for municipal wastewater treatment services, it is necessary to minimize costs subject to the previously specified production function. The cost of municipal wastewater treatment is equal to the sum of the value of the inputs used in the treatment process and an additional component representing the value of the salable byproducts. Salable byproducts are factors that can be varied in order to produce different levels of final output and, as such, can be handled in a manner similar to that used for factors of production. Rather than having a positive price or cost associated with them, though, salable byproducts can be treated as negative costs since they, in fact, represent a source of revenue to the treatment facility. The cost of municipal treatment may then be expressed as:

$$C = \Sigma P_I I - \Sigma P_B B \qquad (3)$$

where:

C = total cost of municipal wastewater treatment,

P_I = a vector of prices of the inputs used in the treatment process, and

P_B = a vector of net prices of the salable byproducts.

The associated total cost function for municipal wastewater treatment can be derived by minimizing the cost equation (3) subject to the production function (2), solving for the first order conditions, and performing the relevant substitutions:

$$C_o = h(F, Q_i, Q_o, Q_E, E, T, P_I, P_B). \qquad (4)$$

Economic theory describes a positive relationship between total costs and the level of output and the prices of inputs. In accordance with theory, then, it is expected that costs are positively related to the flow dimension of output (F), the quality dimension of output as measured by influent characteristics from all sources (that is, Q_i and Q_D), and input prices (P_I). A negative relationship could be expected between costs and effluent characteristics (Q_E), ceteris paribus, since the lower the desired concentrations of pollutants in the effluent (that is, the lower desired Q_E), the higher the level of treatment required and, therefore, the higher the resulting costs of treatment. Finally, costs could be expected to be negatively related to byproduct prices (P_B), since they represent negative costs to the municipality.

Demand for Municipal Wastewater Treatment Services

Generally, there are two major sources of demand for municipal wastewater treatment services: domestic and industrial. Domestic demand includes both residential sources and those commercial sources with wastewater streams similar in composition to residential wastewater streams. Municipal wastewater treatment authorities can influence domestic demand with at least three policy actions. First, sewer systems and treatment plant facilities may be designed to facilitate residential growth and thus have an impact on future demand. Likewise, communities may refuse to expand the physical plant beyond present capacity and thus limit future growth. Second municipal pricing policies for the treatment services may affect the quantity of services demanded by residential and commercial sources. For example, relatively high sewer charges based on use may provide an incentive for individuals to make use of water-saving devices to reduce the quantity of sewage discharged. Finally, the municipal authority can regulate what may be discharged into the sewer system. This type of policy action includes the prohibition on the use of garbage disposal units or the use of detergents containing phosphates.

It can reasonably be assumed, though, that domestic demand is exogenously determined by such factors as population size and not as a result of decisions by municipal wastewater treatment authorities. The linkage between price and quantity, as with many other publicly provided services is relatively weak and indirect, since property taxes and sewer charges related to water use have been the financing alternatives most used in the past. Federal law requires collection of user charges sufficient to finance all operation and maintenance costs, but monitoring and administrative costs will prohibit any individually based charges except for relatively large users such as industrial plants. Domestic users will most likely be treated as a single category and charged an average or representative fee. Thus, the linkage between price and quantity is not expected to strengthen to any large extent.

The assumption of exogenously determined demand for domestic sources seems reasonable, but it will be less representative of many industrial sources. Monitoring and administrative costs for larger volume users will be a small part of total treatment costs. Thus, user fees based on the costs of treating a given firm's wastes and stated in terms of wastewater quantity and quality can be collected from industrial sources. If industrial firms respond to these charges by changing either the quantity or quality of the wastewater they discharge into the municipal system, there will be, as described in the previous section, an impact on municipal wastewater treatment costs. It therefore seems appropriate to examine industrial response to user fees and to present a model of this response that may be integrated into the decision framework of the municipal wastewater treatment authority.

To examine industrial response to user fees, assume a situation in which a firm is discharging its wastes to a municipal wastewater treatment system, and, as commonly is the case, is paying for the treatment services through some combination of property taxes and user charges. 4/ The latter may possibly be based on water use. Assume, further, that the community in which the firm is located is designing a new treatment facility and plans to recover the cost of treating industrial wastes by levying user fees stated in dollars per unit of wastewater characteristics, such as flow and BOD.

Given a shortrun situation in which the firm does not build a new plant, it has three alternatives by which to dispose of its wastewater. One is to discharge all of its wastes to the new municipal system and incur the associated costs. A second is to use inplant removal of pollutants and discharge the remaining effluent to a public waterway. Inplant removal includes both end-of-pipe private wastewater treatment and

4/ The remainder of this section relies in part on material presented in (2, 3).

adjustments in the production process which result in less wastewater (in terms of quantity and/or quality) being produced. Any effluent discharged to public wasterways, though, must meet regulated quality standards. Finally, the firm may use some combination of inplant removal and municipal treatment. That is, it may remove some of the pollutants and discharge those remaining to the municipal system. 5/ These alternatives may be expressed as the following identity:

$$P_T = P_M + P_R + P_D, \tag{5}$$

where:

P_T = a vector of the total quantities of each pollutant produced by the firm in the absence of the user charges,

P_M = a vector of the quantities of each pollutant discharged, by the firm to the municipal wastewater treatment system,

P_R = a vector of the quantities of each pollutant undergoing inplant removal by the firm, and

P_D = a vector of the quantitites of each pollutant discharged into public bodies of water, with

$$P_T, P_M, P_R, P_D \geq 0,$$

$$\text{and } P_M' \; P_D = 0.$$

For example, if the firm discharges all of its wastes to the municipal system, P_T equals P_M, and P_R and P_D equal zero. Likewise, if it uses only inplant removal, P_T equals P_R plus P_D and P_M equals zero. In this case, the quantity of pollutant discharged (P_D) is constrained to a level determined by the flow discharged, times the effluent standard stated in the form of a concentration. Finally, in a situation where the firm performs partial inplant removal and discharges to the municipal system, P_T equals P_M plus P_R, and P_D equals zero.

Handling the flow component of the industrial wastewater during the three alternatives for disposal is more complex than handling the quantities of pollutants and cannot be summarized by one relationship. For example, when the firm discharges all of its wastes to the municipal system, total flow (F_T) equals flow receiving municipal treatment (F_M). In situations where the firm utilizes inplant removal either totally or partially, the disposition of flow depends upon whether it uses end-of-pipe treatment or institutes process changes to reduce water use and, therefore, flow. If the firm uses private end-of-pipe treatment and discharges to public waterways, F_T equals flow undergoing private treatment (F_P) which, in turn, equals flow discharged (F_D). 6/ Similarly, if the firm partially treats its wastes and discharges the remainder to the municipal system, F_T equals F_P which also equals F_M. When a firm alters the production process to reduce water use or installs devices to limit water consumption, the

5/ A fourth alternative may be for the firm to treat part of its wastewater with subsequent discharge to a public waterway and discharge the remaining part to the municipal system. Given the potential economies of size in wastewater treatment and other costs involved in private discharge, it seems unlikely that this situation would even occur. It is, therefore, not considered in the following analysis.

6/ It is generally assumed that the flow entering a treatment facility is equal to that which is discharged.

total flow (F_T) equals flow saved (F_S) plus F_P or F_M, depending upon the final source of treatment.

Assuming the firm does not change its output of the primary product, but is otherwise a profit maximizer, it will respond to the new municipal user fees by minimizing its cost of wastewater disposal. 7/ The firm then compares the cost of municipal treatment (that is, the user fees it is charged) to the cost of inplant removal. The latter represents the least cost condition for inplant waste reduction, including end-of-pipe treatment and production process changes. It also takes into account the corresponding adjustments in other productive inputs. In the previous section, it was shown that wastewater treatment costs depend upon such factors as flow, influent and effluent quality, and factor prices. One would expect that these relationships would hold for private end-of-pipe treatment as well as municipal treatment. While a number of factors can influence the cost of process changes to reduce wastewater generation, it is reasonable to expect that, in general, the marginal cost of inplant removal (MC_R), by either treatment or process changes, increases with the level of inplant removal (P_R). The firm is expected to use those practices which are least costly first, and as higher levels of inplant waste removal are required, costs become progressively greater; that is, each additional unit of waste is more difficult and, therefore, more costly to remove.

These relationships are further illustrated in figure 1 in order to demonstrate the firm's response to the new municipal user fees. The horizontal axis in this diagram represents the level of inplant removal of a certain pollutant by the firm. Its width is determined by the total quantity of the pollutant produced by the firm (P_T). The upward sloping curve represents the marginal cost to the firm of inplant removal (MC_R) of the pollutant, given a certain flow and levels of other pollutants. 8/ This curve extends until it reaches the vertical dashed line which represents the equivalent of the discharge constraint for this pollutant. More specifically, the distance $P_T - P_o$ represents the level of the pollutant that may be legally discharged to public waterways. The MC_R curve is not shown to extend beyond this point source it is assumed that the firm will not remove more of the pollutant than it is required to remove. 9/

Figure 1 can be used to illustrate the firm's response to the new municipal user fees. For simplicity, the following analysis assumes a user fee stated in dollars per unit of the pollutant and constant with respect to the level of this pollutant. When such a user fee is set at zero, the pollutant will undergo no inplant removal. The

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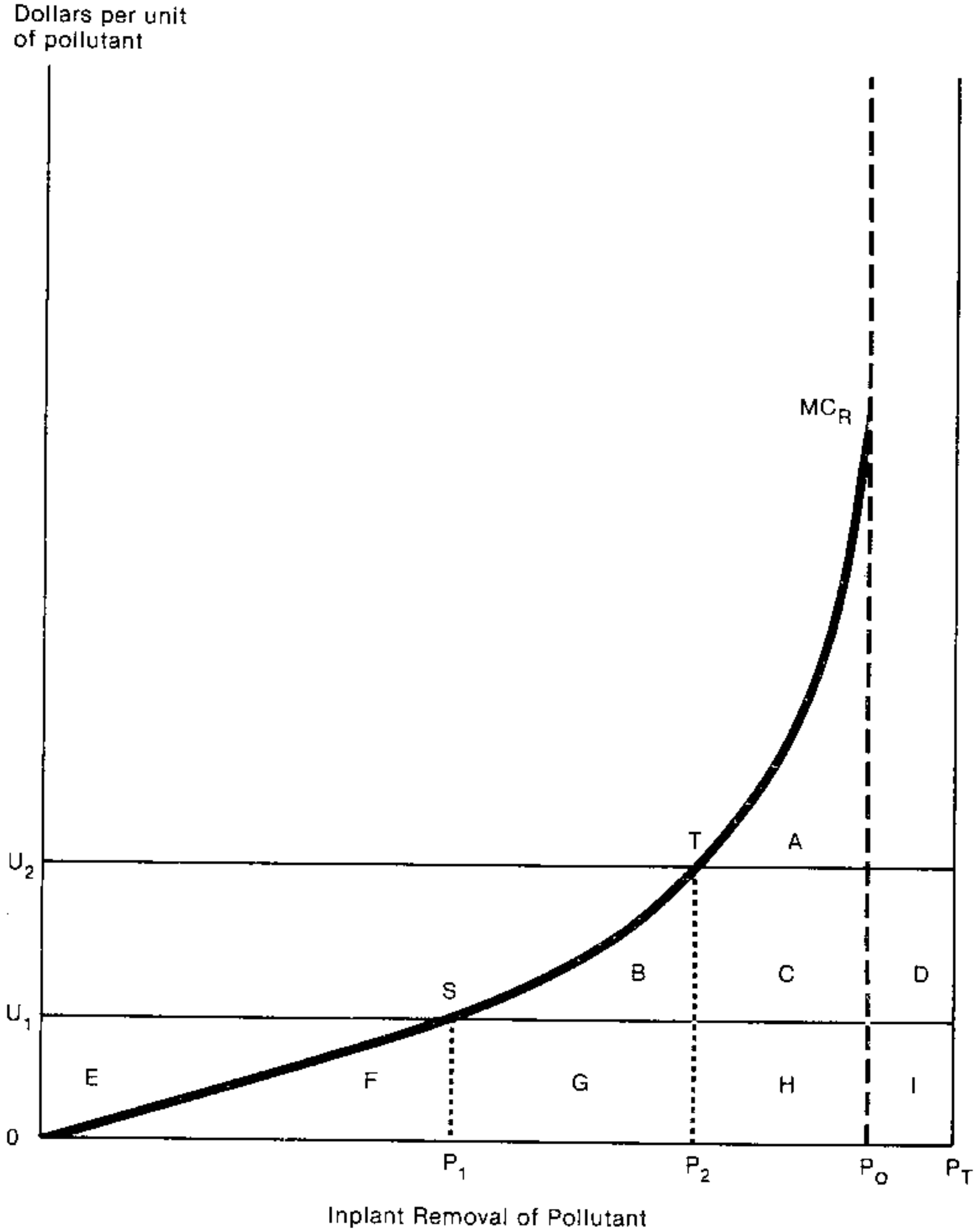
7/ The assumption of constant output is made for simplicity. While the optimal response may be to decrease output, the recovery of byproducts may partially offset this response. If, though, the firm does respond by reducing output, the net result would be to make its demand for municipal wastewater treatment more elastic (2).

8/ The marginal cost curve in figure 1 is depicted as intersecting the vertical axis at the origin. It is drawn this way only for illustrative purposes. It is quite feasible that the true marginal cost of inplant removal curve might intersect either above or below the horizontal axis. For example, there may be a region of waste removal in which byproducts are recovered and produce more than sufficient revenues to cover costs. In this case, there may be a portion of the marginal cost curve which lies below the horizontal axis.

9/ A firm is not normally expected to remove more of a pollutant than is necessary as long as the costs of doing so exceed any associated benefits. There are situations, though, in which actions necessary to meet treatment requirements with respect to one pollutant may lead to incidental removal of others in excess of the regulated levels. This situation occurs due to physical interrelationships among pollutants in both generation and treatment. These interrelationships are discussed in more detail in the procedures section.

Figure 1

Firm's Response to Estabiishment of User Fee Charged Per Unit of Pollutant Discharged to Municipal System



firm will discharge the total quantity of the pollutant it produces (P_T) to the municipal system; that is, P_T equals P_M in equation (5). If a user fee of U_1 is levied, the firm will respond by removing P_1 of the pollutant and discharging the remainder, P_1P_T into the municipal treatment system. This solution is represented by the intersection of the marginal cost of inplant removal with the constant user fee at point S. To the left of the point, per unit inplant removal costs are less than the user charge, so it pays the firm to use inplant removal practices. To the right of S, per unit inplant removal costs are greater than the user charge, so it is less costly for the firm to use municipal treatment.

It may appear that a general operational rule for a firm would be to operate wherever its marginal cost of inplant removal equals the user charge, but one finds that such a generalization is not correct given the situation described above. In this case, only P_0 of the pollutant has to be removed if the firm utilizes inplant removal and discharges to a public waterway, whereas the entire amount of the pollutant (P_T) is the relevant quantity if the firm utilizes partial inplant removal and discharges the remainder to the municipal system. Thus, it is necessary for the firm to compare the total costs of each alternative.

The previous example can be used to illustrate this. At a user fee of U_1, it was concluded that the firm would remove P_1 of the pollutant and discharge the remainder to the municipal system. The total cost of that solution to the firm is given by area F + G + H + I, with F representing the total cost of inplant removal and G + H + I representing the total cost of the user charge for $P_T - P_1$. If the firm used only inplant removal, the total cost would be given by area A + B + C + F + G + H. Area I is less than area A + B + C, so the firm saves by using municipal treatment. By adjusting the level of the user fee upward, a level can be found at which the firm is indifferent to sending the remainder of its wastes to the municipal facility or to treating it privately. User fee U_2 can represent that level for this example. At that fee, the relevant areas to compare are A and D + I. A and D + I are approximately equal, so the firm, while providing at least a level of inplant removal of P_2, is indifferent between providing the additional removal necessary to meet discharge constraints and discharging the remainder to the municipal system. The firm will always use only inplant removal at user fees higher than U_2, since the total cost of doing so is less than any other alternative.

Joint Wastewater Treatment

Municipal wastewater treatment costs are theoretically related to a number of factors, including flow and influent quality. In joint wastewater treatment systems serving small, rural communities, it can be expected that industrial participation will significantly influence both of these factors and, therefore, influence joint treatment costs. It is shown in the previous section, though, that the level of industrial participation in a municipal system should not be considered exogenous. The level of industrial participation depends upon, among other factors, the user fees charged by the municipality. Assuming that user fees are linked to the costs of providing the public treatment, as would be suggested for attainment of a socially efficient allocation of pollution abatement activities, a highly interrelated system actually exists. In terms of the previous example, the user fee will no longer be constant with respect to the quantity of pollutants undergoing inplant removal. Assuming a constant flow, an increase in inplant removal is equivalent to decreasing the concentration of the influent to the public facility. The cost of removing an additional unit of pollutant from a less concentrated influent is generally expected to be higher than the cost of removing it from a more concentrated influent, so the curve in figure 1 representing the user fee will tend to slope upward to the right.

PROCEDURES

Simulation is used to examine the impact of industrial participation costs of providing municipal wastewater treatment services. Two cost simulation models are used to generate cost estimates for separate and joint wastewater treatment. Discharges from a poultry processing plant are used to represent typical industrial wastewater.

Wastewater Treatment Cost Estimation

The basic cost estimates are simulated using the U.S. Army Corps of Engineers CAPDET model, developed to design and evaluate alternative wastewater treatment systems. It contains a library of over 50 unit processes that may be used to treat a variety of parameters in a waste stream. Included in CAPDET are processes providing most conventional and advanced wastewater, sludge, and land treatment. The user of CAPDET must provide certain input data such as the alternative treatment processes to be considered, the appropriate design parameters associated with each treatment process, certain cost estimation parameters, the quantity and quality of influent, and desired quality of effluent. The program combines the treatment processes into viable trains or systems and calculates the operating and maintenance, capital, and equivalent total annual cost of each. 10/ The hypothetical wastewater treatment scheme in figure 2 illustrates some of the alternative treatment trains to provide secondary treatment which may be simulated with CAPDET (15, 16).

A second cost simulation model was employed to estimate the costs of land application of wastewater--the CLAW model (35). CAPDET contains land treatment alternatives, but several technical difficulties were encountered in their use. CLAW also has several features not found in CAPDET, such as a cropping model that simulates crop production operations and calculates corresponding production costs and net revenues.

The CLAW model is based on an EPA cost model as are the corresponding land treatment processes in CAPDET (11). There are five basic operations (with alternative processes for each) incorporated in the CLAW model: pre-application treatment, transmission, storage, application, and effluent recovery. The user of CLAW specifies a set of 37 price and treatment option parameters, and the model simulates the operations of the specified land application systems and estimates capital costs, operating and maintenance costs, net farm revenues, and total costs of each. 11/

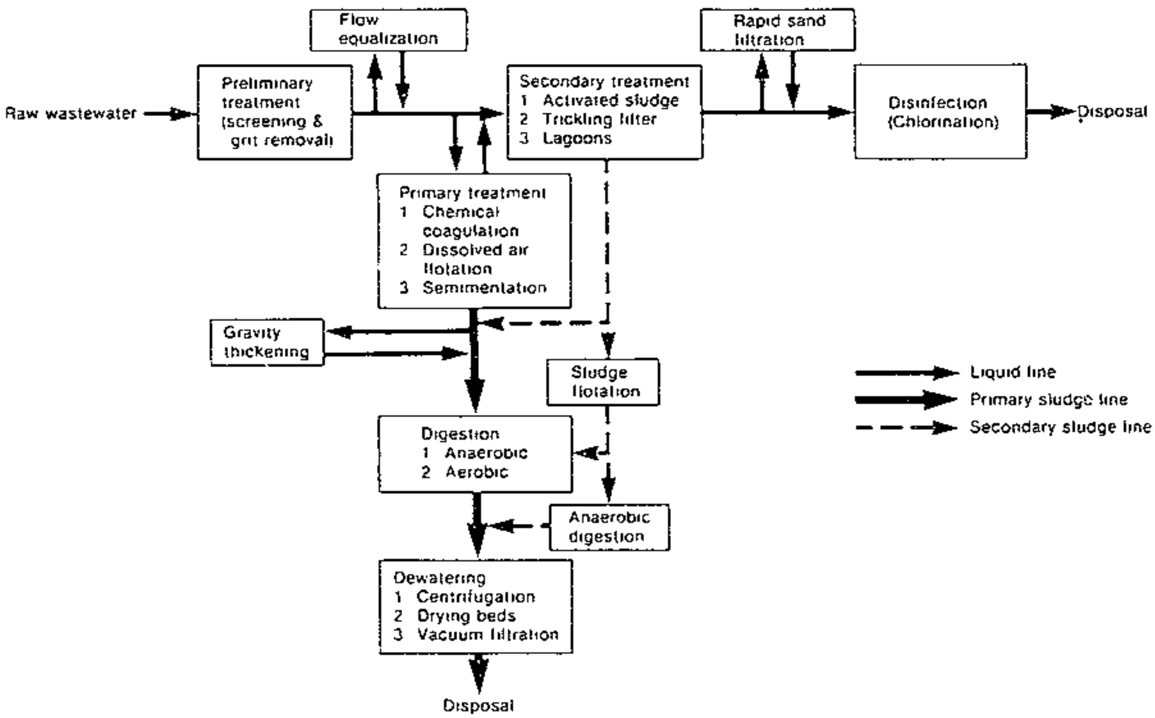
Land application has been used in most municipal treatment systems as an advanced or tertiary treatment technique following existing conventional treatment. With one exception, this study also treats land application as an advanced treatment process following the conventional secondary treatment as simulated by CAPDET; therefore, the cost estimates produced by CLAW are simply added to those from CAPDET to yield total system costs. The exception is a treatment scheme in which CAPDET is used to provide preliminary and primary treatment to the wastewater and CLAW is used to provide the final treatment of the effluent.

10/ The cost estimates produced by CAPDET do not include costs of final disposal of the effluent or sludge, all site-specific costs (such as for land and site preparation), and such overhead expenditures on architect as engineer fees, taxes, and administration.

11/ Unlike the CAPDET model, architectural and engineering fees are included in the capital cost estimates of the CLAW model. The cost estimates of the CLAW model will, therefore, be relatively higher.

Figure 2

Hypothetical Wastewater Treatment Scheme to Provide Secondary Treatment



Thus, the CAPDET and CLAW model are used to estimate the costs of providing municipal wastewater treatment services under various assumptions concerning influent and effluent characteristics (in terms of flow and quality), input and byproduct prices, design criteria, and available technologies. Simulation experiments can be performed to examine the impact on costs of varying these assumptions and additional assumptions concerning institutional rules or policies. An objective of this paper is to analyze the cost impact of industrial participation in municipal treatment system, so specific emphasis is accordingly placed on the particular assumptions relevant to this problem--influent characteristics. The analysis presented does not, however, ignore the implications of the other factors affecting costs, since they define the framework within which the relationships of concern operate. For example, the impact of varying influent characteristics on costs is analyzed, assuming the use of several commonly accepted treatment technologies and effluent criteria.

Poultry Processing Industry

A case study of the poultry processing industry is used to demonstrate the cost impact of industrial participation in municipal treatment systems. 12/ Poultry processing refers to the slaughtering, eviscerating, further processing, and/or packing of young and mature chickens, turkeys, or other fowl. In this

12/ The bulk of the industry is categorized in SIC code 2016, while a portion of it falls into SIC Code 2017.

analysis, poultry processing is limited to the slaughtering, eviscerating, and packing of young chickens, including broiler-fryers, and other young birds such as roasters and capons.

The major processes performed in a poultry processing plant are receiving, killing and bleeding, defeathering, eviscerating, chilling, and packing. The flow of the poultry product through these processes for a typical processing plant is shown in figure 3. This diagram also shows some of the sources of wastewater associated with poultry processing plants. The largest source of wastewater is from cleanup operations, which are not indicated separately on the diagram because they occur in nearly all sections of the plant.

The poultry processing industry was selected as the subject of this study for several reasons. First, poultry processing wastes are similar to the wastes of many other types of firms in the food processing industry (table 1). Therefore, the results of this analysis are similar to those anticipated from applications to other types of firms. Second, poultry-processing firms often utilize municipal treatment services due to the general compatibility of their wastes with municipal wastewater treatment. Finally, firms in this industry frequently locate plants in or near small rural communities. The latter two issues are addressed by two studies based on comprehensive surveys (24, 31).

In the EPA study (24), 153 out of 222 chicken processing plants are reported to use municipal treatment of their wastewaters, while 64 used inplant treatment, and 5 reported using no treatment. A breakdown by size of plant reveals that the proportion of plants using these alternatives remains constant at approximately 70, 28, and 2 percent, respectively, among small, medium, and large plants. 13/

The Vertrees study (31) is more comprehensive in that it reports the number of plants using inplant and municipal treatment by size of plant, size of population center in which the plant is located, and type of treatment system used. The results of the Vertrees study are not totally comparable with those of the EPA study because the former includes all types of poultry processing facilities, not just chicken processing and because it assumes different definitions of small, medium, and large processing plants. 14/ Keeping these differences in mind, several of the Vertrees' findings give a clearer picture of the existing situation in the poultry processing industry.

Of the 386 plants surveyed by Vertrees, 245 use municipal wastewater treatment (table 2). This proportion varies among different size plants (48 percent for small plants, 70 percent for medium plants, and 64 percent for large plants), and among different size communities (between 38 percent for communities of less than 2,500 people and 83 percent for communities of more than 20,000 people). Seventy-six percent of these poultry processing plants examined in this study are located in communities with populations of less than 20,000, and nearly 60 percent of these plants use municipal wastewater treatment services. These proportions are approximately constant across plant sizes, except for the proportion of small plants located in communities

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13/ Small, medium, and large plants are defined by the EPA as plants with average slaughter of 51,000, 95,000, and 207,000 birds per day, respectively (24).

14/ In order to compare the EPA and Vertrees plant size classification, it is necessary to convert them to common units of measurement. When this conversion is done, it is found that a plant in the EPA small-plant category slaughters approximately 46 million pounds per year. This lies somewhat between the Vertrees' medium and large plant categories. Plants in the EPA medium- and large-plant categories would be classified as large by Vertrees.

Figure 3

Flowchart of a Poultry Processing Plant

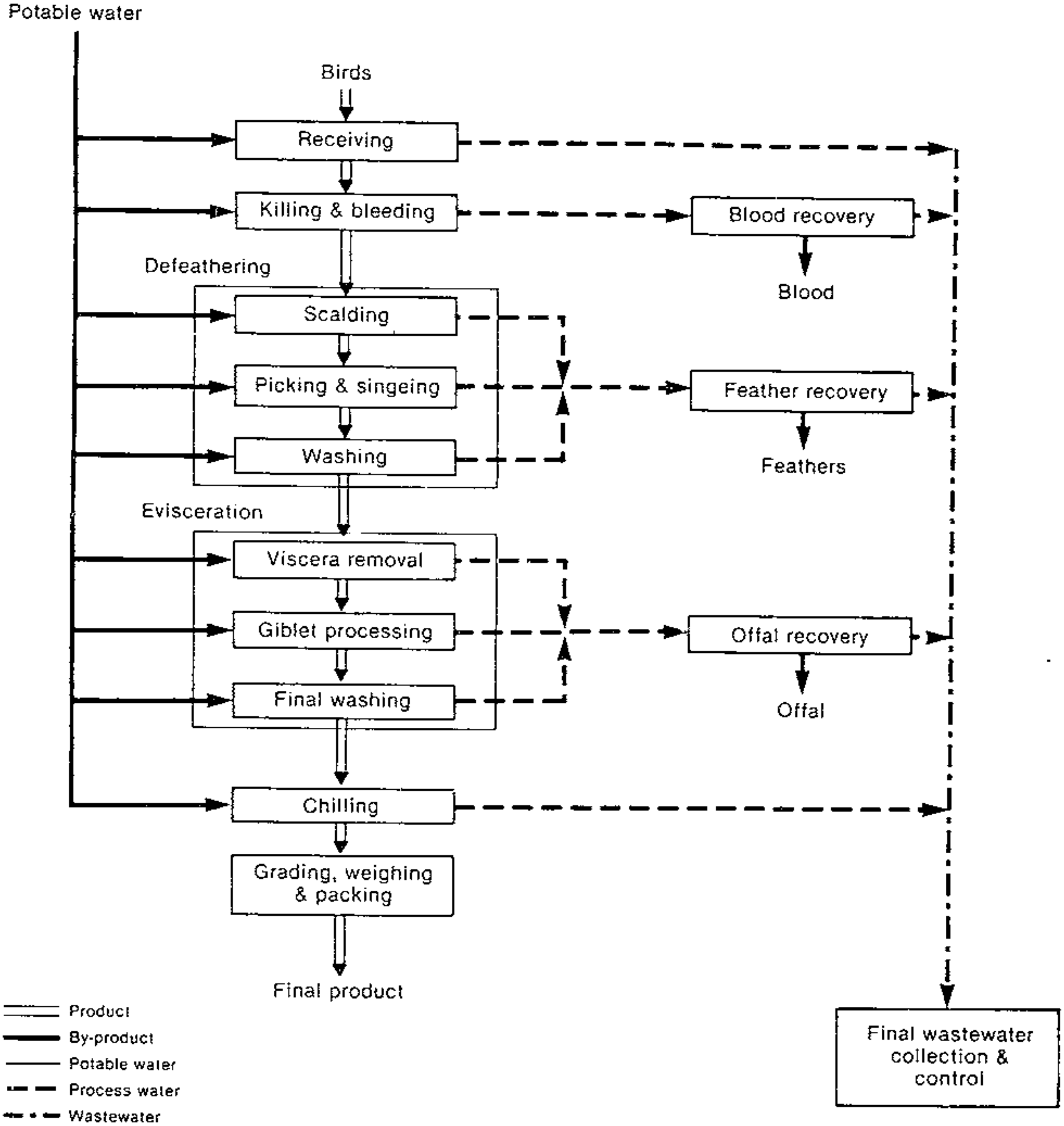

Table 1--Characteristics of wastewater from domestic and food processing sources

Wastewater characteristics	Unit 1/	Domestic wastewater	Food processing wastewater				
			Poultry	Cattle and hogs	Salmon, fresh/frozen	Greenbeans	Tomatoes
Temperature	C°	16	18	NA	7.5	28	NA
Suspended solids	Mg/l	200	340	536	234	129	183-364
Biochemical oxygen demand	do.	200	486	715	484	174	100-610
Chemical oxygen demand	do.	500	968	1,630	814	328	NA
pH	NA	7.3	6.9	NA	7.2	6.1	4.4-10.2
Phosphate	Mg/l	10	19	11	1.8	2	4.4-9.7
Kjeldahl nitrogen	do.	40	90	79	65	NA	2.5-18.2
Ammonia	do.	25	11	12.5	2.4	.3	NA
Nitrite	do.	0	.3	NA	NA	NA	NA
Nitrate	do.	0	.4	.4	NA	.4	NA
Oil and grease	do.	100	207	NA	177	NA	NA

Wastewater characteristics	Unit 1/	Food processing wastewater--continued					
		Corn	Beets	Mixed (corn, plums, broccoli)	Apples	Peaches	Juice (apple, pear, orange)
Temperature	C°	NA	NA	NA	NA	NA	NA
Suspended solids	Mg/l	162-488	402-675	320-580	56-178	725	26-2,510
Biochemical oxygen demand	do.	494-1,400	1,650-4,940	1,182-5,108	748-2,880	940	875-5,300
Chemical oxygen demand	do.	NA	NA	NA	NA	NA	NA
pH	NA	4.6-5.3	5.0	5.3-7.2	7.3-7.4	1,520	5.6-8.2
Phosphate	Mg/l	3-12	4.3-12	1-4.6	9.8-11.2	6.9	.5-3.8
Kjeldahl nitrogen	do.	5.2-14.9	10-16.6	.5-2.5	9-16.8	2.9	.8-18.5
Ammonia	do.	NA	NA	NA	NA	NA	NA
Nitrite	do.	NA	NA	NA	NA	NA	NA
Nitrate	do.	NA	NA	NA	NA	.3	NA
Oil and grease	do.	NA	NA	NA	NA	NA	NA

NA = Not available or not applicable. 1/ Mg/l = milligram per liter.

Sources: (10) for domestic wastewater; (24) for poultry; (33) for cattle and hogs; (6) for salmon; (13) for greenbeans; (1) for tomatoes, corn, beets, mixed, apples, and juice; and (14) for peaches.

Table 2--Distribution of poultry processing plants in Vertrees' survey, by size of population center, size of plant, and location of wastewater treatment

Population	Size of plant (million pounds live weight slaughter): Small (less than 10)		Medium (10 to 49.9)		Large (50 or more)		All	
	Inplant	Municipal	Inplant	Municipal	Inplant	Municipal	Inplant	Municipal
	Number							
Less than 2,500	27	9	42	33	16	11	85	53
2,500-4,000	7	4	7	18	1	9	15	31
5,000-9,999	7	8	3	28	3	7	13	43
10,000-19,999	4	3	7	28	1	11	12	42
20,000 and over	4	21	6	45	6	10	16	76
Total	49	45	65	152	27	48	141	245

of less that 20,000 which use municipal treatment (35 percent). 15/ Approximately two-thirds of all poultry processing plants are currently using municipal wastewater treatment services. This figure is also representative of the plants located in communities of the size on which this study focuses.

A breakdown of poultry processing plants by type of wastewater treatment system used is presented in table 3. The major technologies employed by municipal systems jointly treating poultry processing wastes are activated sludge, trickling filter, and lagoons. These account for over three-fourths of the plants surveyed. There does not appear to be any basic differences between plant sizes. Unlike municipal treatment facilities, private treatment facilities employ lagoons nearly two-thirds of the time, with a few employing activated sludge, and no plants using trickling filter systems. Again, this pattern does not appear to vary among plant sizes. Thus, there is a significant difference between the types of treatment systems employed by inplant and municipal facilities.

Data

The user must provide certain design and cost parameters to estimate the costs of wastewater treatment with the CAPDET and CLAW models. These parameters include the characteristics (in terms of quantity and quality) of the wastewater influent, desired effluent characteristics, the alternative processes to be considered, design specifications of the processes, and input and byproduct prices.

The focus of this study is on municipal wastewater treatment systems in small communities, with populations of 20,000 or less. Six hypothetical sizes of communities will be examined with populations of 3,000, 5,000, 7,500, 10,000, 15,000, and 20,000 in order to isolate the impact of community size. Assuming that average wastewater flows are directly related to population size, such that the average flow per person per day is 100 gallons, the average daily flows associated with these communities are estimated. Minimum and maximum daily flows are derived using the engineering estimation formula presented by the Water Pollution Control Federation (32).

Representative domestic wastewater with the characteristics presented in table 4 is assumed. The majority of the analysis presented in this study will use medium strength (in terms of pollutant concentrations) domestic wastewater. In one section, though, the three quality categories will be used to isolate the sensitivity of treatment costs to influent quality. It is necessary to define a representative poultry processing plant to simulate the impact on municipal wastewater treatment costs of the participation of poultry processing plants in the treatment system. Using average data (24), it is possible to define three representative size poultry-processing plants. A small plant handles approximately 51,000 birds per day and produces roughly 0.5 million gallons per day (mgd) of wastewater, a medium plant handles 95,000 birds per day and produces 0.9 mgd of wastewater, and a large plant handles 207,000 birds per day and produces 1.9 mgd. Minimum daily flows are assumed to be 20 percent of average daily flow, while maximum daily flows are assumed to be 70 percent greater than average daily flows (22).

It is theoretically simple to isolate the impact on municipal treatment costs of individual wastewater characteristics such as BOD, suspended solids, nutrients, and heavy metals, but it is much more complex in practice. The concentrations of the various wastewater constituents are interdependent. For example, an increase in the concentration of BOD is usually accompanied by an increase in the concentration of

15/ This lower use of municipal treatment services in small communities may be due to the unavailability of such services. Also, some of these firms may be located outside of any community.

Table 3--Distribution of poultry processing plants in Vertrees' study, by type of treatment system, size of plant, and location of wastewater treatment

Treatment system	Size of plant (million pounds annual live weight slaughter)							
	Small (less than 10)		Medium (10 to 49.9)		Large (50 or more)		All	
	Inplant	Municipal	Inplant	Municipal	Inplant	Municipal	Inplant	Municipal
	Number							
Primary	13	4	3	24	0	3	16	31
Activated sludge	1	17	5	38	4	22	10	77
Trickling filter	0	10	0	30	0	10	0	50
Lagoons	18	9	41	45	13	12	72	66
Other	5	5	8	15	2	1	15	21
No treatment	12	NA	8	NA	8	NA	28	NA
Total	49	45	65	152	27	48	141	245

NA = Not applicable.

Source: (31).

suspended solids. Likewise, a reduction in BOD through treatment is often accompanied by a reduction in suspended solids. Thus, it is necessary to have an estimate of the interactive effect of BOD and suspended solids in order to isolate the partial effect of BOD on municipal wastewater treatment costs. Specific information about these cross products is not currently available, so the relevant measure of the quality impact on costs for this study is one that incorporates the total quality effect. It will be necessary, then, to use packages of wastewater characteristics to represent quality variation.

The EPA study (24) identifies the average values for raw poultry processing plant wastewater characteristics as presented in table 1. These values are found to be relatively constant for all plant sizes, so they will be assumed for the three hypothetical plants examined in this study. Comparison of these values with the values for medium strength domestic wastewater in table 3 shows the substantially higher concentrations of the wastewater parameters in the poultry processing waste stream. The concentrations of suspended solids, biochemical and chemical oxygen demand (BOD and COD), phosphates, nitrogen, and grease of poultry processing wastes are nearly twice those of the domestic wastes. Except for the relatively high concentration of grease, the poultry processing waste stream is fairly compatible with most treatment systems.

The desired effluent characteristics used in this analysis are the effluent limitations specified by the 1972 Federal Water Pollution Control Act Amendemnts (P.L. 92-500); that is, they are based on secondary treatment. These limitations are equivalent to 30 milligrams per liter (mg/l) for both BOD and suspended solids (21). An additional constraint on the final concentration of phosphates of 1 mg/l will be imposed in a portion of the analysis to determine the impact of industrial participation on tertiary wastewater treatment facilities.

Three general types of wastewater treatment systems are examined in this study: those providing secondary treatment, those providing secondary treatment and phosphorus removal (tertiary treatment), and land treatment systems. 16/ Major emphasis is placed on secondary treatment systems since they occur most frequently. The three most commonly used types of secondary treatment are activated sludge, trickling filter, and lagoons. As shown earlier, these represent nearly 80 percent of the types of municipal treatment currently being used in joint treatment systems involving poultry processing plants (31).

The alternative secondary treatment trains analyzed in this study are presented in figure 2. The liquid line consists of a preliminary screening and grit removal, optional flow equalization and primary clarification, some form of secondary treatment, optional filtration, and chlorination. 17/ Sludges resulting from secondary treatment may be mixed and jointly treated with primary sludges or may receive some amount of separate treatment. The three general types of sludge treatment activities in CAPDET are thickening, digestion, and dewatering. The processes included thus far can be combined to form some 25,344 potential secondary treatment systems.

When the phosphate constraint is imposed on the model, an additional treatment process is included in the liquid line following secondary treatment: two-stage lime treatment. This process is commonly used for phosphorous removal. In addition, a new

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16/ A more detailed explanation of the treatment technologies most commonly used in wastewater treatment is presented in appendix B.

17/ Seven types of activated sludge systems (complete mix, contact stabilization, extended aeration, high-rate aeration, plug flow, pure oxygen, and step aeration), one type of trickling filter system (high rate), and three types of lagoon systems (aerated, aerated facultative, and anaerobic) are included in the analysis.

treatment system is examined in which both secondary and tertiary treatment are provided by two-stage lime treatment followed by carbon adsorption. 18/ No biological treatment is used. This physical-chemical treatment method is not in widespread use today, but is used occasionally.

Land application of the effluent is handled as a tertiary treatment process, except in one case where it is assumed to follow primary treatment. The effluent from CAPDET is, therefore, the influent for CLAW, with the two cost estimates simply being added. Two types of irrigation systems are analyzed: solid set and center-pivot. In both, it is assumed that the effluent is transported 2 miles to the application site via forced-mains and is applied at a rate of 2 inches per week on reed canarygrass. The grass silage produced is valued at $15 per ton. 19/ It is also assumed that the land application system is not the 12 weeks per year used during the winter months.

The design specifications for the individual treatment processes examined in this analysis are average estimates as suggested in (16) and (35). These would normally be adjusted for site-specific conditions. The cost parameters assumed in this analysis are also average values. The interest rate used to amortize the capital cost is 6.61 percent, Moody's municipal bond yield average for 1976. It is felt that this is representative of the opportunity cost of funds to municipalities during that period. A 20-year design life, as recommended by EPA (20), is also used in the amortization calculation. The 1976 EPA indices on sewage treatment plant cost and operation and maintenance cost are employed to update the capital cost and supply cost data, respectively. 20/ The 1976 average hourly earnings for water, steam, and sanitary workers, $5.31 per hour (18), are used as a measure of average wages for operation and maintenance personnel.

Impact of Federal Construction Subsidies

The analysis can be adapted to accommodate the introduction of Federal construction subsidies and to analyze their impact on municipal wastewater treatment facility design and costs. Marshall and Ruegg (7) suggest that construction subsidies, as provided in the 1972 amendments to the Federal Water Pollution Act, will affect the type of treatment processes selected by a community because of differences in capital intensity between processes. The subsidies, therefore, will lead to a different (and possibly inefficient) allocation of resources than would have occurred without the subsidy. This proposition can be tested by comparing cost estimates for the various treatment systems before and after the introduction of the subsidy.

Reduction in Industrial Discharges

In attempts to capture potential economies of size, some small communities have hastily designed and built treatment facilities to handle both domestic and industrial wastes without establishing the proper legal framework to ensure that the anticipated industrial participation is realized. In response to the higher user fees charged by the new facility, firms may reduce the amount of wastes discharged by using some form of inplant treatment. Other firms may disconnect from the municipal system for

18/ Carbon adsorption is used to remove dissolved BOD and COD.

19/ The price of $15 per ton is based on cattle feeding experiments at The Pennsylvania State University and the prices of corn and soybean oil mean in 1976 (36).

20/ Values for the cost indices are from unpublished data, Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C.

reasons unrelated to the fees charged, such as business location changes or closings. In such cases, the community is left with underutilized capacity. 21/

To simulate the impact of the underutilized capacity upon a community's treatment costs, it is assumed that a firm reduces the quantity, but not quality, of wastes it discharges to a joint municipal system. In calculating the new costs of treatment, it is also assumed that total capital cost is unchanged by the decrease in capacity utilization, but that operating and maintenance costs are changed.

One estimate of the new operating and maintenance costs is represented by the corresponding costs for a facility designed to handle the new quantity and quality of influent, with the estimate adjusted to reflect a cost penalty associated with underutilized capacity. The operating and maintenance costs for a facility designed to handle a flow of 1 mgd but actually handling 0.5 mgd, for example, are higher than the costs for a facility designed for a flow of 0.5 mgd. The higher costs can be due to the fixity of such factors as labor; a minimum number of personnel may be required to staff a facility, even though the same personnel are capable of taking on additional responsibilities when higher capacity utilization is reached.

EPA estimated these cost penalties using regression analysis and found that the penalties decrease at a decreasing rate as the percentage of utilization increases. The penalty is 14.6 percent of the total operating and maintenance costs when utilization is between 40 and 60 percent, and 4.4 percent when utilization is between 60 and 80 percent (19). These findings are used to adjust the new operating and maintenance cost estimates described below.

Inplant Waste Removal Cost Estimation

Industrial demand for or use of municipal wastewater treatment services is directly related to the costs of inplant waste removal. These costs represent the least-cost method, including both production process changes which result in less production of wastewater (in terms of quantity and/or quality) and end-of-pipe private treatment of the wastewater.

Wastewater treatment alternatives available to a poultry-processing plant are similar to those of a municipal facility, so the same procedure can be used to estimate costs for both. 22/ Several parameters have to be adjusted, though, to make the analyses comparable. First, the discharge standards for the poultry processing industry are different from those of publicly owned treatment facilities. The July 1, 1977, effluent limitations for this industry are equivalent to 23 mg/l of BOD, 30 mg/l of suspended solids, and 10 mg/l of grease (24). A second adjustment is necessary in terms of the interest rate to be used for capital amortization. The rate selected for this analysis is the 1976 average domestic corporate bond yield of 9 percent (17). This rate approximates the relevant cost of capital to industry. The other cost and design parameters are assumed to be the same as those described previously, since there is no obvious justification for their being different.

The costs of private treatment thus developed represent the total costs a firm will incur if it uses only inplant removal to handle its wastes. These costs are

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21/ The problem of underutilized capacity would be further exacerbated if the plant closing negatively impacts on community size.

22/ As with the cost estimates for municipal treatment facilities, the cost estimates for the private facilities do not include final sludge disposal, administrative, and site-specific costs. In addition, these estimates do not include the cost of obtaining a NPDES permit for direct discharge and do not allow for investment tax credits associated with expenditures on pollution abatement.

comparable to the area under the MC_R curve in figure 1. Due to the interrelationships that exist between the levels of various pollutants in wastewater, it is best to handle poultry-processing wastewater as a package of characteristics and to estimate the cost of treating the package rather than the individual characteristics making up the package. Thus, while the estimated costs can be likened to the area under the MC_R curve, they are not identical to it.

Joint Treatment Decisions in the Poultry-Processing Industry

A firm's decision to use only inplant removal or municipal treatment can be simulated by comparing the total costs to the firm of private treatment with those of joint treatment.

As stressed previously, user fees should be based on the costs of treatment at the public facility to encourage an efficient allocation of resources to pollution abatement. It therefore is assumed that the costs of joint treatment services to the firm are equal to the costs of providing such services by the municipality. Estimates of the latter (developed in a previous section) are then compared to the cost estimates for private treatment. Differences between the two sets of estimates can be expressed as positive or negative cost savings to the firm.

Transmission of Industrial Wastes

Implicit in the above analysis is the assumption that the poultry processing plant is either located next to the new municipal wastewater treatment facility or is on a sewer line capable of handling its wastewater discharge. If this is not the case, it is assumed that the processing plant will be responsible for the costs of transmission of its wastewater to the treatment facility. The associated costs of transmission must then be added to the cost of joint treatment for the relevant comparisons to be made by the poultry processing firms. The remaining cost differences can be expressed in terms of dollars or number of miles from the municipal treatment facility that the firm could be located and be indifferent as to source of treatment. The latter refers to the distance between the firm and the municipal treatment facility which equates the two costs of wastewater treatment to the firm. This latter measure may serve to summarize the larger number of potential results even though it is not relevant to an existing firm.

Two common methods for transmission of wastewater are the gravity flow and the forced-main systems. A technique to calculate the costs of transmission by both alternatives was designed by Young in the development of the CLAW model. 23/ This technique is used to estimate the costs associated with transporting the wastewater for several predetermined distances.

Impact of Federal Construction Subsidies

The impact of the subsidy on industrial participation can also be analyzed. Estimation of the cost to the poultry-processing firm of joint treatment, though, becomes more complicated due to the requirements of the Federal construction subsidy program. At a minimum, the processing firm is required to pay back the portion of the Federal subsidy that is allocable to the treatment of its wastes, in addition to its share of operating and maintenance costs. Is is assumed in the analysis that the firm will be required to pay a charge consisting of the nonsubsidized cost of joint treatment plus a cost recovery fee based on the portion of the subsidy allocable to the

23/ A critical factor in determining transmission costs is the required pipe size. Pipe diameter is determined in Young's model using the Manning and Hazen-Williams equations for gravity flow and forced-main systems, respectively (32).

treatment of its wastes. The latter will be based on the proportion of plant design, in terms of flow, that is due to the firm's discharge. The firm will therefore compare the sum of these charges plus the adjustment for transmission costs with inplant treatment costs. The results of this analysis are then compared with those of the analysis prior to the introduction of the subsidy to examine impact of the subsidy upon potential industrial participation.

Joint Municipal and Industrial Wastewater Treatment

A firm's decision to participate in a joint wastewater treatment system can have an impact on the treatment costs which a community faces and, likewise, a community can affect the level of industrial participation through its pricing decisions. The data generated in the previous sections can be used to demonstrate this simultaneity. In addition, it can be shown that it is possible that the firm and community can bargain for a mutually agreeable charge other than the average costs of joint treatment, and the relevant range of bargaining can be described under a variety of circumstances. The impact of the Federal construction subsidy program upon potential bargaining also can be examined.

MUNICIPAL WASTEWATER TREATMENT COSTS

Industrial participation may have an impact on municipal wastewater treatment costs through two variables: the quantity or flow of wastewater through the treatment facility, and the quality of the influent to be treated. Average treatment costs will generally decrease with increasing volume, *ceteris paribus*, due to economies of size associated with relatively small treatment facilities, and increase with increasing concentrations of contaminants (that is, lower qualities), *ceteris paribus*, due to the additional equipment and/or time requirements to meet the prespecified effluent standards. 24/ The former will be referred to as the "quantity" effect, and the latter as the "quality" effect. The net effect depends upon the particular industry involved and the composition of its wastewaters.

The quantity and quality effects can be illustrated using the quality characterization of domestic wastewaters in table 4. The CAPDET model is used to generate the costs of secondary wastewater treatment systems serving six hypothetical communities with populations between 3,000 and 20,000 (table 5). Costs are estimated for each community assuming weak, medium, and strong strength wastewaters.

The costs used represent the least-cost treatment train for each of the three types of secondary treatment systems: activated sludge, trickling filter, and lagoon. There is some variation in the least-cost designs for the systems treating different combinations of quantity and quality of influent. For example, the least-cost design for activated sludge systems treating all quantities of weak wastes includes preliminary screening and grit removal, primary sedimentation, high-rate activated sludge, chlorination of the effluent, and anaerobic digestion and sand bed drying of the sludge. Medium quality wastes at flows representing populations over 10,000 and strong quality wastes at all flows require the same general design, except for a substitution of contact stabilization activated sludge for the primary sedimentation and

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24/ Average total costs are derived by dividing annual total costs by average daily flow for which the plant is designed, multiplied by 365 days per year. Average total costs are expressed in terms of cents per thousand gallons, since this is the commonly accepted unit of measurement in wastewater treatment design and analysis.

Table 4--Characterization of domestic wastewater

Wastewater parameter	Unit 1/	Quality classification		
		Strong	Medium	Weak
Temperature	°C	16	16	16
Suspended solids	Mg/l	350	200	100
BOD	do.	300	200	100
COD	do.	1,000	500	250
pH	NA	7.3	7.3	7.3
Phosphates	Mg/l	20	10	6
Kjeldahl nitrogen	do.	85	40	20
Ammonia	do.	50	25	12
Nitrites	do.	0	0	0
Nitrates	do.	0	0	0
Oil and grease	do.	150	100	50

NA = Not applicable.

1/ Mg/l = milligram per liter.

Source: (10).

high-rate activated sludge processes. The major change in design for trickling filter systems results in a substitution of anaerobic for aerobic digestion as the strength of the influent increases. Finally, anaerobic lagoons become more cost effective than aerated lagoons at larger volumes for medium and strong wastes.

Each cost figure in table 5 represents some combination of influent flow, population size, and influent quality. Individual columns, however, represent the relationship between average total cost and volume of influent, holding quality constant. Therefore, comparisons of points within a column will yield the quantity effect, whereas comparisons of corresponding points between columns will yield the effect of quality on costs of treatment.

An examination of the costs for activated sludge systems shows that increasing volume (larger populations) leads to lower average costs, while decreasing quality (moving from weak to strong wastewater) leads to higher average costs. More specifically, an increase in plant size from 0.5 to 1 mgd (an increase in population served from 5,000 to 10,000) decreases the average total costs of activated sludge treatment by approximately 24 percent, or 11.2 cents per 1,000 gallons of medium strength influent. This decrease in cost is equivalent to $40,880 per year for a 1-mgd facility. An additional cost savings of 5 cents per 1,000 gallons results from expansion to a

Table 5--Average total costs of domestic wastewater treatment systems providing secondary treatment

Treatment system and population served	Domestic wastewater quality		
	Weak	Medium	Strong
	Cents per 1,000 gallons		
Activated sludge:			
3,000	46.3	57.2	66.7
5,000	37.5	46.5	53.5
7,500	31.8	39.6	45.0
10,000	28.3	35.3	39.8
15,000	24.1	30.0	33.6
20,000	21.6	26.6	29.8
Trickling filter:			
3,000	28.0	48.6	135.5
5,000	23.2	40.2	109.5
7,500	20.0	34.7	92.6
10,000	18.0	31.2	82.3
15,000	15.6	27.1	70.5
20,000	14.1	24.5	62.8
Lagoon:			
3,000	37.1	40.7	43.3
5,000	30.5	33.6	36.0
7,500	26.1	27.8	31.1
10,000	23.4	26.0	28.0
15,000	20.1	22.2	23.9
20,000	18.0	19.9	21.4

1.5-mgd facility. This analysis, then, demonstrates the considerable economies of size associated with treatment facilities serving small rural communities and the decline in importance of these economies as larger and larger volumes are treated.

The impact of influent quality differences on average costs of activated sludge treatment may be observed as the relative difference between the columns. At the smallest population size, the difference between medium and strong strength influent amounts to 9.5 cents per 1,000 gallons, or $10,402 per year. This difference declines to 3.2 cents per 1,000 gallons at the largest population size studies. 25/ Influent qualities are held constant along each column, so the decrease in the difference between the columns must be due to some interactive effect of quality and quantity resulting in a smaller impact of quality differences at higher volumes.

25/ Comparing the absolute difference is somewhat deceiving, since the magnitude of the difference is in part related to the magnitude of the base cost. An examination of the relative differences, in terms of percentage changes, shows that this interactive effect is less important. For example, the absolute differences between the costs of treating medium and strong strength influent are 9.5 cents and 3.2 cents per 1,000 gallons for small (0.3 mgd) and large (2 mgd) volumes respectively, while the percentage changes are 16 and 12 percent.

A similar examination of the data for trickling filter systems reveals the same basic relationships. Again, significant economies of size are found along any particular column. The quality impact on costs (the relative difference between the columns), though, is much larger than that for activated sludge systems. At 0.5 mgd, the increase in costs resulting from treating medium strength as opposed to weak strength wastes is 20.6 cents per 1,000 gallons. The increase resulting from treating strong as opposed to medium strength wastes adds 86.9 cents per 1,000 gallons to total treatment costs. This relatively large impact of quality differences on the costs of trickling filter systems may be explained by the sensitivity of trickling filters to high organic loadings (29). The higher levels of BOD in strong wastewaters will promote faster rates of growth in the micro-organisms attached to the filter media. If these organisms grow enough to plug the passageways through which the wastewater flows, flooding and possibly system failure can occur. Therefore, large expenditures on maintenance are required to prevent these problems. Finally, as with the activated sludge systems, this quality impact diminishes as volumes treated increase.

The final set of data represents the average costs of lagoon wastewater treatment system. The relative differences among columns for these systems are considerably less than those for the other treated systems, indicating that influent quality, within the range examined here, is less important in terms of its impact on costs for lagoon systems. Other than this difference, one again finds the economies of size and the interactive effect of size and quality found in other systems.

An additional comparison can be made on the relative cost-effectiveness of the three secondary treatment systems. Trickling filter systems are cost-effective for communities with weak strength wastewater, but a lagoon system is the lowest cost alternative when wastewaters are medium or strong.

Thus, it is possible, using hypothetical wastewater streams representative of normal domestic sewage, to isolate and examine the impacts on treatment costs of differences in flow and influent quality. As hypothesized, the larger design flows decrease average treatment costs per 1,000 gallons due to economies of size, while lower influent qualities (higher pollutant concentrations) increase average treatment costs. The analysis also shows that the magnitude of the quality effects depends on the type of treatment technology used and the volume of influent to be treated.

Joint Wastewater Treatment Costs

The costs of joint treatment of domestic and poultry processing wastewaters are analyzed for the six hypothetical community sizes. Cost estimates are for medium strength domestic wastes plus wastes from small, poultry processing plants. Treatment costs are then generated for 24 wastewater influent streams, varying in flow and concentrations of certain wastewater characteristics.

Secondary Treatment

The average wastewater treatment costs for facilities providing secondary treatment to the various combinations of domestic and poultry processing plant wastes appear in table 6. A comparison of costs associated with the three types of secondary treatment shows that lagoon systems are the most cost-effective with and without the inclusion of a poultry processing plant. Trickling filter systems are less costly than activated sludge systems when only medium strength domestic wastes are treated, but the reverse is true when the treatment of poultry processing wastes is added. There is some effect upon the designs of the least-cost trains. The primary adjustment in the activated sludge systems, due to the different composition of influent, is a substitution of contact stabilization for chemical coagulation coupled with high-

Table 6--Average total costs of secondary wastewater treatment systems and joint treatment with poultry processing plants

Treatment system and population served	Domestic wastewater	Joint wastewater by size of plant		
		Small	Medium	Large
	Cents per 1,000 gallons			
Activated sludge:				
3,000	57.2	45.2	39.6	32.1
5,000	46.5	40.4	36.7	30.5
7,500	39.6	36.2	33.7	29.0
10,000	35.3	33.2	31.3	27.5
15,000	30.0	28.8	27.7	25.2
20,000	26.6	26.0	25.2	23.4
Trickling filter:				
3,000	48.6	91.9	78.9	63.5
5,000	40.2	83.1	74.2	60.8
7,500	34.7	76.1	68.8	58.0
10,000	31.2	70.4	64.7	55.6
15,000	27.1	62.4	58.4	51.7
20,000	24.5	56.8	54.0	48.7
Lagoon:				
3,000	40.7	30.7	27.0	22.3
5,000	33.6	28.0	25.5	21.3
7,500	27.8	25.6	23.8	20.4
10,000	26.0	23.8	22.3	19.5
15,000	22.2	21.0	20.0	18.0
20,000	19.9	19.1	18.4	17.0

rate activated sludge. Contact stabilization appears to be the least-cost alternative when average daily flow exceeds 1.5 mgd. For trickling filter systems, the least-cost treatment train includes chemical coagulation and filtration when treating only domestic wastes. These unit processes are omitted from the least-cost treatment train when poultry processing wastes are included. Accompanying this adjustment is a substitution of anaerobic digestion of sludges for aerobic digestion. Finally, anaerobic lagoons are more cost-effective than aerated lagoons when domestic population equals or exceeds 10,000 or when a large poultry processing plant is present. This change in cost-effectiveness does not result from changes in flow alone, but from some combination of flow and influent quality.

Activated Sludge

Focusing first on the average total costs of the least-cost activated sludge treatment trains, one finds that each cost figure in table 6 represents a different combination of quantity and quality of influent. Thus, comparisons, whether along a single column or between columns, will not yield the separate effects of quantity or quality, but a combined or net effect on treatment costs. Exceptions to this are comparisons along the domestic wastewater column. As in the previous section, analysis of this column demonstrates the considerable economies of size associated with treatment facilities of the scale hypothesized here. The quality of the influent remains constant along this column, so comparisons of points along the column reveal the cost savings resulting from the quantity effect alone (economies of size).

Cost reductions from moving down the other columns result from both quantity and quality effects. That is, volume naturally increases as higher volumes of domestic wastewater are jointly treated with a fixed volume of poultry processing wastewater, resulting in additional economies of size. Concentrations of pollutants decrease due to the dilution effect of the addition of the less-polluting domestic wastes, resulting in additional cost savings. Both of these effects, though, decline in importance as larger volumes are reached.

Analysis of the relative differences between the curves shows that joint treatment, no matter what the size of the poultry processing plant, results in a substantial cost reduction for any size of community examined. This reduction for the smallest community size (3,000) amounts to approximately 21 percent, or 12 cents per 1,000 gallons, for inclusion of a small poultry processing plant; 31 percent, or 17.6 cents per 1,000 gallons, for a medium plant; and 44 percent, or 25.1 cents per 1,000 gallons, for a large plant. These reductions fall to 2.3, 5.3, and 12 percent (or 0.6, 1.4, and 3.2 cents per 1,000 gallons), respectively, when the largest community size (20,000) is considered. Per capita cost reductions resulting from treating poultry processing wastes in addition to the normal domestic loads range between 22 cents a year for a small plant in the largest community, to $9.16 a year for a large plant located in a small community. 26/

The cost reductions just described may also be explained in terms of quantity and quality effects. Total volume again increases as higher volumes of poultry processing wastewater are added to a fixed volume of domestic wastewater but the resulting concentration of pollutants also increases. Hence, the two effects operate in opposite directions. The net result is a reduction in costs, so the quantity effect must be dominant. 27/

Trickling Filter

Analysis of the domestic wastewater column for trickling filter systems again demonstrates the economies of size associated with smaller treatment facilities. Examination of the other columns also shows general cost reductions attributable to increasing community size. As with activated sludge, these reductions may be explained by reinforcing quantity and quality effects.

The major difference in the results of the two analyses lies in the relative differences between the columns. Whereas the addition of poultry processing wastewater results in a reduction in average annual treatment costs in the case of activated sludge systems, it results in substantially higher costs for trickling filter systems. The additions to average costs from inclusion of small, medium, and large poultry processing plants are 89, 62, and 27 percent (or 43.3, 30.3, and 12.9 cents per 1,000 gallons), respectively, for the smallest community size, and 132, 121, and 99 percent (or 32.3, 29.6, and 24.2 cents per 1,000 gallons), respectively, for the largest community size. Thus, the inclusion of poultry processing wastewater in a trickling filter treatment system results in substantial cost increases. 28/

26/ These calculations assume that total treatment costs are allocated to individual and industrial sources on the basis of the design flow attributed to each.

27/ The quality effect will be examined in more detail later in the analysis.

28/ This assumes medium strength domestic influent. The cost increases are less if strong domestic influent is assumed.

These differences are again explained through the use of quantity and quality effects. As previously noted, trickling filter treatment is very sensitive to influent quality and particularly sensitive to high organic loadings. The raw poultry processing wastewater has more than twice the BOD concentration of medium strength domestic wastewater, so adding it to a trickling filter system severely affects efficiency and leads to higher per unit costs. Thus, including a poultry processing plant in the design of a municipal wastewater treatment system using trickling filters causes a very large quality effect that dominates the quantity effect accompanying the larger volume. 29/

Lagoon

Analysis of the corresponding average annual costs for the least-cost lagoon treatment systems reveals results similar to those for activated sludge treatment systems. Lagoon treatment systems also exhibit considerable economies of size which, in general, result in cost reductions when poultry processing plant wastes are jointly treated with those from domestic sources.

Quality Effect for Secondary Wastewater Treatment

It is the net impact on costs of industrial participation that is of primary interest here, but it is possible, given the data, to isolate and examine the quality effect. To perform this analysis, it is necessary to hold volume constant and allow the concentration of pollutants to vary. The quality effect is isolated in table 7 by holding total wastewater flow (mgd) constant and increasing the pollutant concentrations in the influent by altering the proportion of the wastewater originating from industrial sources.

The average total costs of wastewater treatment increase as the concentrations of the pollutants in the influent increase. For example, average costs are 30 cents per 1,000 gallons for a 1.5 mgd activated sludge system treating domestic wasteater only. If the mix of the influent is altered to include 1 mgd of domestic wastewater and 0.5 mgd of poultry processing wastewater (the equivalent of a small processing plant), average costs increase to 33.2 cents per 1,000 gallons. Increasing the wastewater influent concentrations to reflect the presence of a medium-size poultry processing plant (0.9 mgd) and a population of 6,000 (0.6 mgd) raises costs to 35 cents per 1,000 gallons.

There are similar cost responses for lagoon systems, but costs for trickling filter systems are considerably larger. Inclusion of the wastes from a small poultry processing plant in a 1.5-mgd treatment facility results in approximately a 160-percent increase in average treatment costs. Costs are 27.1 cents per 1,000 gallons for domestic wastes only, while treating 1 mgd of domestic wastes plus 0.5 mgd of poultry processing wastes costs 70.4 cents per 1,000 gallons.

There appears to be a threshold effect associated with the introduction of the poultry processing wastes to trickling filter systems. A large cost increase occurs when small amounts of processing wastes are included. The additional increase in concentration of pollutants resulting from the substitution of a medium-sized poultry

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29/ Average flows are held constant, but maximum and minimum flows do change. A separate analysis shows that while peak flows have a minor impact upon treatment costs, minimum flows have no impact within a reasonable range. The lower peak flows resulting from inclusion of poultry processing wastes tend to decrease costs, thus lowering any estimate of a separate quality effect.

Table 7--Average total costs and wastewater influent characteristics for a 1.5-mgd joint secondary treatment facility

Items	Domestic wastes only	Domestic and small plant	Domestic and medium plant 1/
		Cents per 1,000 gallons	
Treatment system:			
Activated sludge	30.0	33.2	35.0
Trickling filter	27.1	70.4	71.0
Lagoons	22.2	23.8	24.7
Wastewater influent characteristics:			
		Million gallons per day	
Domestic flow	1.5	1.0	.6
Industrial flow	0	.5	.9
		Milligrams per liter	
Suspended solids	202	247	284
BOD	200	295	372
COD	500	656	781
Phosphate	10	13	15
Kjeldahl nitrogen	40	57	70
Oil and grease	100	136	164

1/ The cost estimates for this combination of domestic and poultry processing wastewater are extrapolated from the corresponding graphs.

processing plant for a small one increases average total costs by relatively smaller amounts. 30/

Thus far, the independent effects of quantity and quality and the corresponding net effect on the costs of secondary wastewater treatment systems resulting from industrial participation have been shown. The substantial economies of size exhibited by all three types of secondary treatment systems are sufficient to result in reduced per unit treatment costs when the inclusion of poultry processing wastewater is incorporated into the design of municipal treatment facilities using activated sludge and lagoon systems. The higher levels of BOD in poultry processing wastewater reduces the efficiency of trickling filter systems so as to lead to a net increase in per unit treatment costs when included in such a system. This analysis will be expanded in the next section to include tertiary treatment systems for phosphorus removal.

30/ A separate analysis shows that while the costs of trickling filter system are insensitive to small changes in BOD, there is a rather large increase in costs at a concentration of approximately 250 mg/1. Apparently there is a threshold value for BOD concentrations in trickling filters, that when reached, required large expenditures to prevent system failure.

Inplant Tertiary Treatment

An additional constraint is placed on effluent quality in order to examine the impact of industrial participation upon the costs of tertiary wastewater treatment systems: the concentration of phosphates is limited to 1 mg/l. Three inplant tertiary treatment systems are analyzed: physical-chemical, activated sludge followed by two-stage lime addition for phosphorous removal, and trickling filter also followed by two-stage lime addition. The physical-chemical system consists of a two-stage lime process with carbon adsorption of dissolved BOD or COD.

The average costs of tertiary treatment for the various combinations of domestic and poultry processing plant wastewater are presented in table 8. 31/ A comparison of

Table 8--Average total cost of inplant tertiary wastewater treatment systems

Treatment system and population served	Domestic wastewater	Joint wastewater by size of plant		
		Small	Medium	Large
	Cents per 1,000 gallons			
Physical-chemical:				
3,000	79.4	45.0	36.5	27.3
5,000	56.4	39.2	33.3	26.0
7,500	43.9	34.4	30.3	24.7
10,000	37.1	31.0	28.0	23.5
15,000	29.7	26.5	24.7	21.6
20,000	25.6	23.7	22.4	20.2
Activated sludge-lime addition:				
3,000	108.7	67.6	55.9	42.7
5,000	79.8	59.2	51.2	40.5
7,500	63.4	52.1	46.6	38.4
10,000	54.3	47.1	43.1	36.4
15,000	44.2	40.3	37.8	33.2
20,000	38.2	35.9	34.1	30.8
Trickling filter-lime addition:				
3,000	83.1	116.6	97.1	74.8
5,000	59.2	103.9	89.7	71.5
7,500	46.2	93.0	82.7	68.0
10,000	39.1	85.2	77.2	65.1
15,000	31.4	74.5	69.2	60.3
20,000	27.1	67.3	63.4	56.6

31/ As with the secondary treatment systems, relatively minor adjustments are necessary in the least-cost treatment designs when poultry processing wastes are introduced.

costs shows the physical-chemical treatment system as being cost-effective for all combinations of wastewater. As with the secondary treatment system, trickling filters are less costly when only medium strength domestic wastes are treated, but activated sludge is less costly when joint wastes are treated.

All three types of tertiary systems exhibit relatively large economies of size. The resulting cost reductions from higher volumes are larger than those for secondary systems. For example, the reduction in average cost accompanying an increase in design volume from 0.5 mgd to 1 mgd for an activated sludge tertiary system treating only domestic influent is 25.5 cents per 1,000 gallons (or a 32-percent reduction), while the corresponding reduction for an activated sludge secondary system is 11.2 cents per 1,000 gallons (or 24 percent).

The participation of poultry processing plants in municipal systems providing the physical-chemical and activated sludge-lime addition tertiary treatment results in considerably large cost savings due to the relatively large economies of size associated with these systems. In addition, these economies also appear to be responsible for a moderation of the cost increases accompanying the inclusion of poultry processing wastes to tertiary treatment systems utilizing trickling filters and lime addition.

Land Application Tertiary Treatment

Land application will basically be considered as another form of tertiary treatment. It is assumed that the effluent from the secondary treatment facilities is used in either of two-spray irrigation systems: solid-set or center-pivot. The CLAW model is used to simulate these systems and to generate the corresponding net average costs. 32/ The irrigation cost estimates are then added to the cost estimates for secondary treatment to derive system costs.

The costs of irrigation generated by CLAW appear in table 9. Center-pivot irrigation is more cost effective for the range of volumes considered here. Also, the average costs of both techniques are lower for larger populations and the inclusion of poultry processing plants. The effluent is constrained to a certain level of quality, so the reductions in costs associated with these changes are due to volume effects alone. Wastewater treatment systems using secondary treatment followed by land application of the effluent will tend to experience rather large cost reductions as facility size is expanded due to participation of poultry processing plants, except in the case of trickling filter systems which have been shown to be very sensitive to influent quality.

Analysis of table 10 confirms this proposition. One finds rather large potential cost savings available when poultry processing wastes are jointly treated with domestic wastes. For example, the participation of small, medium, and large poultry processing plants in treatment systems utilizing activated sludge and center-pivot irrigation reduces average costs for the smallest community by 51.4, 65.8, and 81.9 cents per 1,000 gallons, respectively. These costs savings are considerably less for larger communities, as would be expected. As with inplant tertiary treatment, there is considerable moderation of the quality effect of industrial participation on trickling filter systems. The relatively large quantity effect tends to partially negate the cost increases resulting from the addition of the more concentrated poultry processing wastes.

32/ The net costs of the irrigation systems are equal to the costs of the irrigation system minus any net farm revenues associated with the sale of the irrigated crops.

Table 9--Average total costs of land application of the effluent from joint wastewater treatment systems

Treatment system and population served	Domestic wastewater	Joint wastewater by size of plant		
		Small	Medium	Large
	Cents per 1,000 gallons			
Solid-set irrigation:				
3,000	113.8	75.3	66.5	58.3
5,000	89.4	70.4	64.1	57.3
7,500	77.0	65.8	61.4	56.3
10,000	70.4	62.9	59.9	55.7
15,000	62.9	59.0	57.3	54.5
20,000	59.0	56.9	55.7	53.4
Center-pivot irrigation:				
3,000	106.9	67.5	58.7	50.1
5,000	81.7	62.6	56.2	49.1
7,500	69.2	57.9	53.4	48.0
10,000	62.6	55.0	51.6	47.4
15,000	55.0	50.9	49.1	46.1
20,000	50.9	48.7	47.4	45.0

Since land application is assumed to be used as tertiary treatment, it seems natural to compare the cost estimates for these systems with those for the inplant tertiary treatment presented in table 8. A comparison of the two tables reveals that, *ceteris paribus*, the physical-chemical system assumed in this analysis provides a tertiary level of treatment at least cost. In general, though, both this and the activated sludge-lime addition systems tend to be less costly for all combinations of wastewaters than the land application. 33/ The trickling filter-lime addition system is less costly than land application systems for treating only domestic wastewater, but the larger economies of size and smaller quality effects allow the land application systems (other than the one assuming trickling filter secondary treatment) to be less costly when poultry processing wastes are included.

Impact of Federal Construction Subsidies

It is assumed in this section that the community meets construction subsidy requirements and will receive a 75-percent subsidy from the Federal Government. This

33/ Finding inplant tertiary treatment less costly, at least for domestic wastewater, tends to contradict earlier findings by Young and Carlson (37) and Pound, Crites, and Smith (12). Both of the earlier studies found land application to be more cost effective. Several reasons may be offered to explain this apparent contradiction. In this study, the cost of final sludge disposal and administrative costs are not included. These may be significant, especially when lime addition is utilized due to the large quantities of chemical sludges. Also, unlike earlier studies, this one analyzes numerous designs of treatment systems to select the least-cost design.

Table 10--Average total costs of center-pivot irrigation systems

Treatment system and population served	Domestic wastewater	Joint wastewater by size of plant		
		Small	Medium	Large
	Cents per 1,000 gallons			
Primary:				
3,000	137.7	90.0	79.4	67.4
5,000	107.1	83.9	75.9	65.8
7,500	91.1	77.4	71.6	64.0
10,000	82.3	73.1	68.7	62.8
15,000	72.1	67.1	64.7	60.4
20,000	66.4	63.6	61.9	58.6
Activated sludge:				
3,000	164.1	112.7	98.3	82.2
5,000	128.2	103.0	92.9	79.6
7,500	108.8	94.1	87.1	77.0
10,000	97.9	88.2	82.9	74.9
15,000	85.0	79.7	76.8	71.3
20,000	77.5	74.7	72.6	68.4
Trickling filter:				
3,000	155.5	159.4	137.6	113.6
5,000	121.9	145.7	130.4	109.9
7,500	103.9	134.0	122.2	106.0
10,000	93.8	125.4	116.3	103.0
15,000	82.1	113.3	107.5	97.8
20,000	75.4	105.5	101.4	93.7
Lagoon:				
3,000	147.6	98.2	85.7	72.4
5,000	115.3	90.6	81.7	70.4
7,500	97.0	83.5	77.2	68.4
10,000	88.6	78.8	73.9	66.9
15,000	77.2	71.9	69.1	64.1
20,000	70.8	67.8	65.8	62.0

subsidy applies to all capital expenditures including land for land treatment operations, but does not apply to expenditures necessitated for special handling of industrial wastes. The average local costs of treating various combinations of domestic and poultry processing wastewater by the treatment systems described thus far are presented in table 11. 34/ Table 11 shows that while the absolute levels of costs may be lower after the subsidy is applied, general trends found in previous sections of this study are still exhibited. For example, the quantity effect of poultry processing plant participation still tends to dominate the quality effect for treatment systems other than trickling filters. The resulting cost reductions also tend to decline at higher volumes and increase for higher levels of treatment.

34/ Average local total costs are equal to average total costs without the subsidy minus the amount of the subsidy.

Table 11--Average local total costs of joint wastewater treatment systems

Treatment system	Domestic wastewater by size of community			Joint wastewater by size of plant and community								
				Small plant			Medium plant			Large plant		
	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000
	Cents per 1,000 gallons											
Secondary:												
Activated sludge	36.6	22.3	17.1	28.4	20.9	16.5	25.0	19.5	15.7	19.6	16.9	14.5
Trickling fitler	31.7	20.7	16.4	75.9	58.4	47.2	64.4	53.1	44.5	50.6	44.9	39.6
Lagoons	29.5	16.3	12.6	22.3	14.6	11.9	19.6	13.5	11.4	13.3	11.8	10.4
Inplant tertiary:												
Physical-chemical	37.6	20.4	15.1	24.6	17.9	14.2	20.8	16.6	13.7	16.5	14.4	12.6
Activated sludge	56.4	31.0	22.8	38.3	27.7	21.4	32.5	25.7	20.3	25.0	21.5	18.4
Trickling filter	38.8	21.1	15.6	86.9	65.5	52.5	72.9	59.3	49.4	56.3	49.8	43.8
Land application:												
Solid-set irrigation--												
Primary	58.2	36.5	29.8	40.9	33.0	28.7	36.1	31.2	28.0	31.0	28.7	26.7
Activated sludge	76.2	46.5	37.1	54.5	42.4	35.5	47.8	39.7	34.3	39.3	35.5	32.2
Trickling filter	71.3	44.9	36.4	102.0	79.9	66.3	87.2	73.3	63.1	70.3	63.5	57.3
Lagoon	69.1	40.5	32.6	48.4	36.1	31.0	42.4	33.7	30.0	33.0	30.4	28.1
Center-pivot irrigation--												
Primary	57.9	35.3	28.4	39.7	31.7	27.3	34.9	29.9	26.5	29.5	27.2	25.1
Activated sludge	75.9	45.3	35.7	53.3	41.1	34.1	46.6	38.4	32.8	37.8	34.0	30.6
Trickling filter	71.0	43.7	35.0	100.8	78.6	64.9	86.0	72.0	61.6	68.8	62.0	55.7
Lagoon	68.8	39.3	31.2	47.2	34.8	29.6	41.2	32.4	78.5	31.5	28.9	26.5

It has been argued that subsidies of construction costs alone will lead to a bias toward the selection of more capital-intensive treatment systems (7). Communities, it is argued, will select the system that incurs least local costs, which may now differ from social costs (such as environmental protection). While this is theoretically correct, there is little evidence of such a bias exhibited in the data (table 11). There may have been some relative differences in the impacts on the costs of the treatment systems analyzed in this study, but these impacts are not sufficient to change the original ranking in terms of costs of comparable treatment systems. Thus, while there is a potential impact on efficiency created by subsidies for construction costs alone, cost differentials between different treatment methods may prevent the realization of these impacts.

The bias and resulting inefficiencies of the construction subsidy program, though, may be more subtle. This program creates the potential for a community to select an entirely different treatment system, and it may also have an impact on the design of a particular system. For example, a lagoon treatment system may still be the cost effective form of secondary treatment after application of the subsidy, but the particular type of lagoon system or the processes, such as primary treatment or filtration that complement it, may change in attractiveness.

In order to examine the potential for more subtle types of changes to occur, the average local total costs of the second least-cost design for the various general types of treatment and wastewater loads are derived (table 12). There are indeed some changes in the rankings when total costs are compared to the least-cost design estimates. That is, when the subsidy is accounted for, some of the previous least-cost designs are no longer the least costly. Changes occur in some systems, including activated sludge, physical-chemical, and lagoon treatment. The major change occurring in the activated sludge and physical-chemical systems designs is a substitution of aerobic for anaerobic digestion, while the change in the lagoon systems is a substitution of anaerobic for aerated lagoons. The penalty to society for selection of a less cost-effective treatment design in each particular case examined here is rather small (less than 2 cents per 1,000 gallons), but the aggregate effect upon society, when all subsidized construction is considered, may be substantial. For example, difference in costs of 1 cent per 1,000 gallons for facilities serving a total population of 1 million translates into a cost difference of $365,000 per year.

Impact of a Reduction in Industrial Discharges

To examine the cost implications to a community of underutilized capacity resulting from reduced industrial discharges, assume a situation in which a medium-size poultry processing plant (one handling 95,000 birds per day and producing 0.9 mgd of wastewater) is participating in a municipal treatment system designed to treat its wastes and waste from a domestic population of 10,000 to a secondary treatment level.

Estimates of the average costs of the joint treatment facilities to the community when a firm reduces its discharges are presented in table 13. Data in the first column represent a situation in which the firm does not reduce wastes and will serve as a reference point. The second and third columns represent cases in which there is a uniform reduction in terms of flow and quality of the wastes discharged by the firm such that it discharges 0.5 mgd (or the equivalent of a small plant) rather than 0.9 mgd.

Thus, the new operating and maintenance costs are based on those for a joint facility designed to handle the wastes from a small processing plant but adjusted using the EPA results described previously. The only difference in the data presented in the second and third columns is the assumption concerning the industrial share of the treatment costs. In the second column, it is assumed that the firm pays a user

Table 12--Average local total costs of the second least-cost joint wastewater treatment systems

Treatment system	Domestic wastewater by size of community			Joint wastewater by size of plant and community								
				Small plant			Medium plant			Large plant		
	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000
	Cents per 1,000 gallons											
Secondary:												
Activated sludge	36.3	22.5	17.1	28.2	21.1	16.9	24.9	20.0	16.5	20.5	17.9	15.5
Trickling filter	32.2	21.1	16.7	76.7	58.6	47.4	65.0	53.3	44.7	50.8	45.1	39.8
Lagoon	25.8	18.7	14.7	19.0	17.2	14.2	16.5	16.3	13.8	16.5	14.7	13.0
Inplant tertiary:												
Physical-chemical	37.6	20.3	15.3	24.4	17.8	14.1	20.7	16.4	13.6	16.4	14.3	12.5
Activated sludge	56.5	31.2	22.9	38.2	27.7	21.8	32.6	25.5	21.0	25.7	22.3	19.3
Trickling filter	39.2	21.4	15.8	87.6	66.0	52.8	73.4	59.7	49.7	56.7	50.1	44.1
Land application:												
Solid-set irrigation--												
Primary	58.7	36.8	30.1	41.4	33.4	29.0	36.6	31.6	28.3	31.4	29.0	27.0
Activated sludge	75.9	46.7	37.1	54.3	42.6	36.0	47.7	40.2	35.1	40.2	36.5	33.2
Trickling filter	71.8	45.3	36.7	102.8	80.1	66.5	87.8	73.5	63.3	70.5	63.7	57.5
Lagoon	65.4	42.9	34.7	45.1	38.7	33.3	39.3	36.5	32.4	36.2	33.3	30.7
Center-pivot irrigation--												
Primary	58.4	35.6	28.7	40.2	32.1	27.6	35.4	30.3	26.8	29.9	27.5	25.4
Activated sludge	75.6	45.5	35.7	53.1	41.3	34.6	46.5	38.9	33.6	38.7	35.0	31.6
Trickling filter	71.5	44.1	35.3	101.6	78.8	65.1	86.6	72.2	61.8	69.0	62.2	55.9
Lagoon	65.1	41.7	33.3	43.9	37.4	31.9	38.1	35.2	30.9	34.7	31.8	29.1

charge based on the new total flow, whereas in the third column it is assumed that the firm pays the same per unit charge as before the reduction in the amount of wastes discharged. The final column represents a situation in which the firm stops discharging into the municipal system altogether. The new operating and maintenance costs can then be estimated by adjusting the corresponding costs for a facility treating only a 1-mgd flow of domestic wastewater, although designed for a 1.9-mgd flow of combined wastewaters.

Table 13 shows that the cost impact to communities from reduced poultry processing plant participation in the joint treatment facility is substantial for all three secondary treatment technologies. For example, systems utilizing activated sludge treatment experience increases in average treatment costs of 6.2 or 9.3 cents per 1,000 gallons (depending upon the assumption concerning industrial user fees) when the firm partially reduces its discharges, and 19.1 cents per 1,000 gallons when the firm stops discharging altogether. On an annual basis, these increases correspond to $22,630, $33,945, and $69,715, respectively, for a community of 10,000. A similar analysis can be used to show the impact of a reduction in a community's population.

Thus, failure to enter into long-term contracts with participating firms can result in considerable cost penalties to the community. The size of the penalty for a given size community and given size plant will depend upon the pricing policy for industrial users and the amount of reduction. In general, the penalty is greater when the community does not adjust its user fees to incorporate the new level of flow and when the reduction is greater. An exception to the latter occurs when the municipal facility utilizes trickling filter treatment and the firm stops discharging. In this

Table 13--Average total cost of joint wastewater treatment to a community of 10,000 when a medium-size poultry processing plant reduces wastes discharged to municipal system

Treatment system	Reduction in wastes discharged (million gallons per day) 1/			
	0	0.4 2/	0.4 3/	0.9
	Cents per 1,000 gallons			
Without subsidy:				
Activated sludge	31.3	37.5	40.6	50.4
Trickling filter	64.7	76.3	82.1	49.0
Lagoon	22.3	26.7	29.0	37.1
With subsidy: 4/				
Activated sludge	19.5	22.6	24.1	28.0
Trickling filter	53.1	61.7	65.9	27.1
Lagoon	13.5	15.7	16.8	20.4

1/ Assumes operating and maintenance costs with new flow plus a penalty for underutilized capac ty.
2/ Assumes firm pays per unit charge based on new flow.
3/ Assumes firm pays same per unit charge as before reduction.
4/ Assumes 75-percent construction subsidy with industrial cost recovery requirements.

situation, the reduction in operating and maintenance costs due to the reduction in organic material to be treated by the facility is large enough to result in lower average costs to the community.

Also presented in table 13 are estimates of the corresponding costs to the community if it receives a 75-percent Federal construction subsidy. The Federal Government now assumes a portion of the capital costs, so the costs penalty to the community resulting from the underutilized capacity is substantially reduced. For systems using activated sludge treatment, costs increase 3.1 (or 4.6) and 8.5 cents per 1,000 gallons, respectively, for the two levels of industrial participation with the subsidy as opposed to 6.2 (or 9.3) and 19.1 cents per 1,000 gallons without the subsidy. It can therefore be concluded that there may be less incentive with the subsidy program for communities to seek long-term contracts with poultry processing plants using their services. Thus, the potential exists for a misallocation of resources for pollution abatement.

POULTRY PROCESSING PLANT WASTEWATER TREATMENT COSTS

The reactions of industrial wastewater dischargers must be understood if communities are to properly design and operate joint treatment facilities. Some advantages and disadvantages to the municipality have been outlined. Industrial plant managers will evaluate the relative costs of providing their own treatment compared with joining a municipal system. The following sections examine private and joint treatment from the firm's perspective, including the costs of transmitting the wastewater to the municipal treatment facility.

Private Inplant Treatment Costs

Industrial demand for municipal treatment services is theoretically related to the costs of alternatives to municipal services. The general compatibility of poultry processing wastes with domestic wastewater means this industry has similar options available for treating its wastes as does the municipal treatment authority. Thus, the same general procedures used in the previous section to generate municipal treatment costs are applicable to generate private treatment costs.

The CAPDET and CLAW models can be used to simulate private treatment of poultry processing wastewater with minor modifications in the cost of capital and effluent standards. The simulations are performed for hypothetical poultry processing plants, which differ only in the number of birds processed per day, and for the same types of technologies considered previously. 35/

The average total costs of the least-cost treatment designs for the poultry processing plants are presented in table 14. Lagoon systems provide cost-effective secondary treatment. The sensitivity of trickling filters to the low-quality wastes makes the corresponding costs for these systems considerably higher than the others; these costs are over 100 percent greater than activated sludge systems.

The average costs for the different size plants decline as plant size increases. This decrease is due solely to the quantity effect, since wastewater quality is assumed to be constant for all plant sizes. In general, the rate of decrease in

35/ When the simulations are performed, the least-cost treatment designs are similar to those for the municipal facilities. In addition, these designs do not differ significantly for the different size processing plants.

Table 14--Average total costs of wastewater treatment at a poultry processing plant

Treatment system	Size of plant		
	Small	Medium	Large
	Cents per 1,000 gallons		
Primary	31.1	25.6	20.0
Secondary:			
Activated sludge	63.3	50.6	38.3
Trickling filter	136.8	108.5	81.9
Lagoon	48.4	38.9	29.6
Inplant tertiary:			
Physical-chemical	69.0	48.6	32.8
Activated sludge-lime addition	101.4	73.9	51.5
Trickling filter-lime addition	162.2	121.5	86.3
Land application:			
Solid-set irrigation	105.8	86.0	71.2
Primary	136.9	111.6	91.2
Activated sludge	169.1	136.6	109.5
Trickling filter	242.6	194.5	153.1
Lagoon	154.2	124.9	100.8
Center-pivot irrigation	94.6	76.4	61.4
Primary	125.7	102.0	81.4
Activated sludge	157.9	127.0	99.7
Trickling filter	231.4	184.9	143.3
Lagoon	143.0	175.3	91.0

costs declines as volume increases. For example, the difference in average costs for activated sludge systems between a small processing plant (producing 0.5 mgd of wastewater) and a medium plant (producing 0.9 mgd of wastewater) is 12.7 cents per 1,000 gallons, whereas the difference between the medium and large (producing 1.9 mgd of wastewater) plants is 12.3 cents per 1,000 gallons. These cost savings are equivalent to $41,720 and $85,300 per year for medium and large plants, respectively. 36/

The cost estimates for inplant tertiary treatment again demonstrate the cost advantages of physical-chemical systems. In fact, the costs associated with this system make it competitive with the activated sludge and more than competitive with the trickling filter secondary treatment systems. Analysis of the cost differences between the three plant sizes for inplant tertiary systems shows relatively large economies of size. The average costs of systems serving large processing plants are approximately half those of systems serving small plants.

36/ It has been argued that effluent restrictions that apply to all firms in an industry, regardless of size, will discriminate against smaller firms because of the large economies of size associated with wastewater treatment (9). This analysis serves to provide evidence in support of this contention. The average costs of meeting the same restrictions on effleunt for a large poultry processing plant are considerably less than those for a smaller plant.

Center-pivot irrigation in land application systems is less costly than solid-set. Rather large cost differences exist between systems serving different size plants. For example, a center-pivot irrigation system with activated sludge pretreatment costs 30.9 and 58.2 cents per 1,000 gallons less to operate for medium- and large-size plants, respectively, than for small plants. Comparisons of the costs of land application and inplant tertiary systems again show cost advantages for the larger plant.

Joint Wastewater Treatment Costs

A firm will compare the cost it must incur for municipal treatment to the costs of inplant waste reduction in deciding how to handle its wastewater. The costs of end-of-pipe wastewater treatment at the plant were estimated for three sizes of poultry processing plants in the last section and are assumed to represent the costs of alternative waste reduction to the corresponding plants.

User fees should represent the costs of treating the wastes at the public treatment facility in order to stimulate efficient levels of private versus public wastewater treatment. The user fees assumed in this analysis, then, are equal to the costs of joint treatment developed previously. They will depend upon the quantity and quality of wastes discharged by the firm, the population for which the public facility is designed, and the type of technology to be used at the facility.

A summary of the average costs of private treatment at the plant and average costs of joint treatment at the municipal facility is presented in table 15, which permits simulation of a number of possible poultry processing firm decisions. For example, assume that a small poultry processing plant is located in a community of 3,000 residents that is planning a new wastewater treatment facility, that both the plant and the community are required to treat their wastes to a secondary level of treatment, and that both plan to use the least-cost method to attain the level of treatment. Lagoon systems provide this level of treatment at least cost for both the processing plant and the municipality, so the plant decisionmaker will compare the cost of providing the plant's own lagoon treatment (48.4 cents per 1,000 gallons) with the cost of lagoon treatment at the municipal facility (30.7 cents per 1,000 gallons). 37/ The processing plant can save 17.7 cents per 1,000 gallons (or $32,302 per year) by discharging to the municipal system rather than performing its own treatment.

Comparisons, such as the one just performed, can be made for each community and plant size and each type of treatment technology. Such comparisons show potential cost savings available to the poultry processing firm with the use of municipal treatment. These cost savings are less for larger populations and plant sizes and greater for higher levels of treatment (inplant tertiary and land treatment).

Several factors are responsible for the cost savings exhibited when municipal treatment services are used. First, the discharge standards are more stringent for the poultry processing plant, thereby requiring more pollutant removal. The private firm is also assumed to face higher financing costs for its capital (9 percent versus 6.61 percent). The most important factor, though, is the economies of size associated with wastewater treatment. Average treatment costs decline rather rapidly as volume

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37/ It is assumed, at this point, that the only costs to the firm of using municipal treatment are user fees equal to the cost of joint treatment. Costs of transmission of the plant's wastewater to the public facility are assumed to be zero. This latter assumption is relaxed in a later section.

Table 15--Comparison of average total costs of private treatment at poultry processing plant with average total costs of joint treatment at the municipal facility

Treatment system	Treatment by size of plant and community											
	Small plant				Medium plant				Large plant			
	Private treatment	Joint treatment 1/			Private treatment	Joint treatment 1/			Private treatment	Joint treatment 1/		
		3,000	10,000	20,000		3,000	10,000	20,000		3,000	10,000	20,000
	Cents per 1,000 gallons											
Secondary:												
Activated sludge	63.3	45.2	33.2	26.0	50.6	39.6	31.3	25.5	38.3	32.1	27.5	23.4
Trickling filter	136.8	91.9	70.4	56.8	108.5	78.9	64.7	54.0	81.9	63.5	55.6	48.7
Lagoon	48.4	30.7	23.8	19.1	38.9	27.0	22.3	18.4	29.6	22.3	19.5	17.0
Inplant tertiary:												
Physical-chemical	69.0	45.0	31.0	23.7	48.6	36.5	28.0	22.4	32.8	27.3	23.5	20.0
Activated sludge	101.4	67.6	47.1	35.9	73.9	55.9	43.1	34.1	57.5	42.7	36.4	30.8
Trickling filter	162.2	116.6	85.2	67.3	121.5	97.1	77.2	63.4	86.3	74.8	65.1	56.6
Land application:												
Solid-set irrigation--												
Primary	136.9	98.7	81.0	71.8	111.6	87.2	77.0	70.2	91.2	75.6	71.1	67.0
Activated sludge	169.1	120.5	96.1	82.9	136.6	106.1	91.2	80.9	109.5	90.4	83.2	76.8
Trickling filter	242.6	167.2	133.3	113.7	194.5	145.4	124.6	109.7	153.1	121.8	111.3	102.1
Lagoon	154.2	106.0	86.7	76.0	124.9	93.5	82.2	74.1	100.8	80.6	75.2	70.4
Center-pivot irrigation--												
Primary	125.7	90.9	73.1	63.6	102.0	79.4	68.7	61.9	81.4	67.4	62.8	58.6
Activated sludge	157.9	112.7	88.2	74.7	127.0	98.3	82.9	72.6	99.7	82.2	74.9	68.4
Trickling filter	231.4	159.4	125.4	105.5	184.9	137.6	116.3	101.4	143.3	113.6	103.0	93.7
Lagoon	143.0	98.2	78.8	67.8	115.3	85.7	73.9	65.8	91.0	72.4	66.9	62.0

1/ The average total costs of joint treatment for the three population sizes are abstracted from the data presented in previous tables.

increases, so the higher volume afforded by joint treatment causes costs to be lower. 38/ Economies of size become exhausted at higher and higher volumes, so cost savings to the processing firm from joint treatment tend to decline as populations and plant sizes become larger. The larger cost savings for inplant tertiary and land treatment systems are also explained by this effect.

Comparisons are not limited to only those under the assumption that both the processing plant and municipal facility will use the same type of treatment. A possible situation is one in which the processing plant is free to use the least-cost treatment system (say lagoons), but the municipal facility is constrained to use another type (activated sludge or trickling filter). 39/ In this situation, the firm may find either cost savings of a lower magnitude (when the municipal facility uses activated sludge treatment) or zero or negative cost savings (when the municipal facility uses trickling filter treatment). Thus, the constraint on the municipal treatment facility may have an impact on industrial participation.

Positive Transmission Costs

The analysis, up to this point, assumes that the poultry processing plants are either located next to the treatment facility or next to a sewer line with sufficient capacity to handle the plant's wastewater discharge. This may not be the case in many situations, and the expense of providing transportation of the wastes to the municipal facility must be incurred by the poultry plant.

Two common methods of sewage transport are gravity transmission and forced-main transmission. The method developed by Young (35) is used to estimate the costs associated with transporting poultry processing plant sewage via each of these methods. The resulting cost estimates are presented in table 16, showing that the costs of forced-main transmission are generally larger than those of gravity transmission. This difference, of course, is due to the added expense of pumping equipment. The difference in cost, however, declines at larger distances. This may be explained by the relatively large friction losses associated with gravity transmission. Larger and more expensive pipes are required because of these friction losses.

There are some economies of size associated with both methods; average costs are less to pump a large volume the same distance as a small volume. The per unit costs of transporting the wastes of a large processing plant via gravity transmission are nearly a third of the per unit costs of transporting the wastes of a small plant. Finally, a more careful analysis reveals that the relationship between average costs and distance is discontinuous. Differences in pipe size and pumping head requirements are partially responsible for these discontinuities.

Assuming, as is quite feasible under current laws, that the firm will be responsible for any expenses incurred in the special handling of its wastes, then the true cost of municipal treatment to the firm will be the sum of the costs of joint treatment plus transmission. Thus an additional variable may enter into the decision

38/ There is a dilution effect in addition to a volume effect from jointly treating poultry processing wastes with the weaker domestic wastewater. This dilution or quality effect declines as poultry plant size increases and contributes to the decline in cost savings as plant size increases.

39/ Municipal treatment facilities, being public utilities, are much more subject to regulations than private facilities. There is some uncertainty concerning the reliability of lagoon systems and there are potential aesthetic arguments against lagoons, so there are situations in which lagoons are not likely to be used by municipal facilities.

Table 16--Average total costs of transporting poultry processing plant wastewater to the municipal treatment facility

Type of transmission and miles between processing plant and treatment facility	Size of plant		
	Small	Medium	Large
	Cents per 1,000 gallons		
Gravity:			
1	6.7	4.0	2.1
2	13.7	8.1	4.3
3	20.2	12.8	6.8
4	26.8	16.9	9.6
5	35.6	21.0	12.0
6	42.6	26.6	15.3
7	49.6	31.0	17.8
8	56.6	35.3	20.3
9	63.6	39.7	24.1
10	75.0	47.2	26.8
15	112.2	70.7	42.2
20	158.0	100.4	59.1
25	197.3	133.1	73.8
30	236.6	159.6	92.7
Forced main:			
1	19.2	12.6	8.1
2	27.6	17.6	11.1
3	35.4	22.7	14.5
4	43.7	28.1	17.2
5	50.8	32.4	19.5
6	58.0	36.7	22.8
7	65.1	41.8	25.3
8	71.4	48.1	27.8
9	79.4	52.7	30.3
10	90.0	57.4	35.0
15	125.8	78.8	48.7
20	161.5	107.2	61.4
25	213.2	130.5	79.5
30	252.1	163.6	93.2

framework of the firm when it is determining the least-cost method of handling its wastes. This variable is the distance between the firm and the municipal treatment facility. One way to account for this variable in the current study would be to repeat the analysis presented earlier in this section with differing assumptions concerning distance. This procedure, though, would be rather tedious and time consuming. An alternative procedure would be to identify the maximum distance a firm would be willing to transport its waste to a municipal treatment facility; that is, the distance which equates the cost of municipal treatment (cost of treatment and transmission) to the cost of private treatment of its wastewater.

The latter procedure is used in the development of table 17. The values presented in table 17 represent the maximum distances a poultry processing plant might be expected to transport its wastes in order to use municipal treatment services. These

Table 17--Distance between poultry processing plant and municipal treatment facility which equates the cost of private treatment to the cost of joint treatment plus transmission 1/

Treatment system 2/	Size of plant and community								
	Small plant			Medium plant			Large plant		
	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000
	Miles								
Secondary:									
Activated sludge	2	4	5	2	4	5	2	4	5
Trickling filter	6	9	10	6	9	10	7	9	10
Lagoon	2	3	4	2	3	4	3	4	5
Inplant tertiary:									
Physical-chemical	3	5	6	2	4	5	2	3	5
Activated sludge	4	7	9	4	6	9	3	5	8
Trickling filter	6	10	10	5	9	10	4	8	10
Land application:									
Solid-set irrigation--									
Primary	5	7	9	5	7	9	6	7	9
Activated sludge	6	9	10	6	9	10	7	9	10
Trickling filter	10	10	15	10	10	15	10	10	15
Lagoon	6	9	10	7	9	10	7	9	10
Center-pivot irrigation--									
Primary	4	7	8	5	7	9	5	7	8
Activated sludge	6	9	10	6	9	10	6	9	10
Trickling filter	9	10	15	10	10	15	10	10	15
Lagoon	6	9	10	6	9	10	7	8	10

1/ Assumes gravity transmission of the wastewater.
2/ Assumes that both the plant and the municipal facility use the same type of treatment.

values are derived by comparing the difference between the cost of private and joint treatment (calculated from table 15) with the cost of gravity transmission presented in table 16. For example, given the situation described earlier in which a small poultry processing plant is located in a small community (population 3,000), and assuming that both the plant and municipal authority can use the least-cost secondary treatment technology (lagoons), then the cost difference, is 17.7 cents per 1,000 gallons. A comparison of this figure with the costs of gravity transmission of wastes from a small plant presented in table 16 indicates that the firm would be willing to transport the sewage between 2 and 3 miles. For simplicity, the lower figure is what appears in the appropriate location in table 17. The other mileages in this table are developed in a similar manner.

Careful examination of table 17 reveals that the breakeven distances for a given type of treatment system and a given population size varies very little among plant sizes. Given the decrease in potential costs as larger plants are considered (due to economies of size in transmission), these distances would be expected to increase. Apparently, these two effects balance each other, thereby causing little change in the breakeven distances as plant size varies.

The presentation in table 17 only permits analysis of situations in which the firm and the municipal facility utilize the same type of treatment. A situation in which the public facility is constrained in the choice of treatment it uses can be examined in table 18 which contains the maximum distances between the poultry processing plant and the municipal facility the firm would be willing to transport its wastes, assuming that the facility uses lagoon treatment. Data in table 18 show that, due to the higher costs associated with activated sludge and trickling filter treatment, the plant would be less willing to transport wastewater when the municipality is restricted to these types of treatment. The cost savings at higher populations are sufficient to permit the plant to transport its wastes some distance to a municipal facility using activated sludge, but the sensitivity to influent quality of trickling filter facilities rules out such incentives.

Impact of Federal Construction Subsidies

Construction of a municipal treatment facility subsidized under the Federal grants program does not mean the cost of municipal treatment to industry is simply a user charge based on average municipal costs. Recipients of the subsidies are required to establish a system to collect from industrial users that portion of the subsidized capital costs attributable to the treatment of the wastes from those users. In addition, the recipients are required to collect from all users the portions of operating and maintenance costs attributable to the treatment of the corresponding discharges.

One method of allocating costs is to base each user's proportion of costs upon its proportion of total flow. 40/ Using this method, the subsidized capital costs of the municipal facility can be allocated among its industrial users. This procedure is applied to the three different size poultry processing plants for the treatment systems examined previously. Resulting industrial cost recovery charges appear in table 19. Data show the same basic relationships as exhibited by the costs upon which these figures are based. Cost recovery charges, as with average treatment costs, tend to decline with higher volumes from either domestic or industrial sources, and tend to increase as the level of treatment increases.

40/ The interdependencies between the various constituents of quality, such as BOD and suspended solids, and between these and flow, limit the use of a system that allocates costs on the basis of flow and quality separately.

Table 18--Distance between processing plant and municipal treatment facility which equates the average costs of lagoon treatment at the plant to the average costs of treatment at the municipal facility plus transmission 1/

Treatment system and population served	Size of plant		
	Small	Medium	Large
		Miles	
Activated sludge:			
3,000	0	N	N
5,000	1	0	N
7,500	1	1	0
10,000	2	1	0
15,000	2	2	2
20,000	3	3	2
Trickling filter:			
3,000		N	N
5,000	N	N	N
7,500	N	N	N
10,000	N	N	N
15,000	N	N	N
20,000	N	N	N
Lagoon:			
3,000	2	2	3
5,000	3	3	3
7,500	3	3	3
10,000	3	3	4
15,000	4	4	4
20,000	4	4	5

1/ Assumes gravity transmission of the wastewater.
2/ N means the firm is not willing to utilize municipal treatment given the assumptions concerning the form of user fee and the form of the liability with respect to transmission costs.

The procedure just illustrated provides a method to allocate the subsidized portion of municipal wastewater treatment costs, but the community, at a minimum, must also allocate operating and maintenance costs to its users. Allocation according to average flow is again a reasonable alternative. It is assumed that the community will attempt to allocate all nonsubsidized costs, including both operating and maintenance costs, and any remaining capital costs. Thus, the total charge to industrial users will be the sum of the cost recovery charge and average local total costs, as presented in table 12. These charges are derived to develop the correct decision framework for industrial users (table 20).

Table 20, as with table 15, permits a direct comparison of the costs of private versus public wastewater treatment which confront poultry processors. The basic relationships exhibited in the earlier table do not change appreciably. Again, public facilities can provide the services at a lower cost when similar treatment systems are used by both private and public facilities. In addition, costs are generally lower for municipal treatment even when different (but comparable in terms of level of treatment) systems are used. The major exception to this generalization is municipal systems

Table 19--Average industrial cost recovery charge for joint wastewater treatment systems 1/

Treatment system	Size of plant and community								
	Small plant			Medium plant			Large plant		
	3,000	10,000	20,000	3,000	10,000	20,000	3,000	10,000	20,000
	Cents per 1,000 gallons								
Secondary:									
Activated sludge	9.2	6.7	5.2	8.0	6.4	5.2	6.8	5.8	4.9
Trickling filter	8.7	6.5	5.3	7.9	6.3	5.2	7.0	5.8	4.9
Lagoon	4.6	5.0	3.9	4.0	5.5	3.8	4.9	4.2	3.6
Inplant tertiary:									
Physical-chemical	11.2	7.2	5.2	8.5	6.2	4.8	5.9	5.0	4.2
Activated sludge	16.0	10.6	7.9	12.8	9.5	7.5	9.7	8.2	6.8
Trickling filter	16.2	10.7	8.1	13.2	9.8	7.7	10.1	8.3	7.0
Land application:									
Solid-set irrigation--									
Primary	29.7	24.4	21.7	26.1	23.0	21.2	22.5	21.3	20.2
Activated sludge	34.2	27.5	24.0	30.0	26.1	23.6	26.0	24.2	22.5
Trickling filter	33.7	27.3	24.1	29.9	26.0	23.6	26.2	24.2	22.5
Lagoon	29.6	25.8	22.7	26.0	25.2	22.2	24.1	22.6	21.2
Center-pivot irrigation--									
Primary	26.1	20.7	17.0	22.5	19.3	17.5	18.8	17.6	16.5
Activated sludge	30.6	23.8	20.2	26.4	22.4	19.9	22.3	20.5	18.8
Trickling fiter	30.1	23.6	20.3	26.3	22.3	19.9	22.5	20.5	18.8
Lagoon	26.0	22.1	18.9	22.4	21.5	18.5	20.4	18.9	17.5

1/ Industrial cost recovery charges are based on average flows.

Table 20--Comparison of average total costs of private treatment at the poultry processing plant with average total costs of subsidized joint treatment at the municipal facility 1/

Treatment system	Small plant: Private treatment	Small plant: Joint treatment 1/ 3,000	Small plant: Joint treatment 1/ 10,000	Small plant: Joint treatment 1/ 20,000	Medium plant: Private treatment	Medium plant: Joint treatment 1/ 3,000	Medium plant: Joint treatment 1/ 10,000	Medium plant: Joint treatment 1/ 20,000	Large plant: Private treatment	Large plant: Joint treatment 1/ 3,000	Large plant: Joint treatment 1/ 10,000	Large plant: Joint treatment 1/ 20,000
	Cents per 1,000 gallons											
Secondary:												
Activated sludge	63.3	45.8	29.0	22.3	50.6	36.4	25.9	20.9	38.3	26.4	22.7	19.4
Trickling filter	136.8	84.6	64.9	52.5	108.5	72.3	59.4	49.7	81.9	57.6	50.7	44.5
Lagoon	48.4	34.1	21.3	16.5	38.9	26.3	19.0	15.2	29.6	18.2	16.0	14.0
Inplant tertiary:												
Physical-chemical	69.0	48.8	27.6	20.3	48.6	33.1	22.8	18.5	32.8	22.4	19.4	16.8
Activated sludge	101.4	72.4	41.6	30.7	73.9	51.1	35.2	27.8	51.5	34.7	29.7	25.2
Trickling filter	162.2	103.1	76.2	60.6	121.5	86.1	69.1	57.1	86.3	66.4	58.1	50.8
Land application:												
Solid-set irrigation--												
Primary	136.9	65.3	57.4	50.4	111.6	62.2	54.2	49.2	91.2	53.5	50.0	46.9
Activated sludge	169.1	88.7	69.9	59.5	136.6	77.8	65.8	57.9	109.5	65.3	59.7	54.7
Trickling filter	242.6	135.7	107.2	90.4	194.5	117.1	99.3	86.7	153.1	96.5	87.7	79.8
Lagoon	154.2	78.0	61.9	53.7	124.9	68.4	58.9	52.2	100.8	57.1	53.0	49.3
Center-pivot irrigation--												
Primary	125.7	65.8	52.4	45.2	102.0	57.4	49.2	44.0	81.4	48.3	44.8	41.6
Activated sludge	157.9	83.9	64.9	54.3	127.0	73.0	60.8	52.7	99.7	60.1	54.5	49.4
Trickling filter	231.4	130.9	102.2	85.2	184.9	112.3	94.3	81.5	143.3	91.3	82.5	74.5
Lagoon	143.0	73.2	56.9	48.5	115.3	63.6	53.9	47.0	91.0	51.9	47.8	44.0

1/ The average total costs of subsidized joint treatment for the three population sizes are derived by adding the average local total costs and the average industrial cost recovery charge.

providing secondary treatment with trickling filters. For tertiary treatment, though, such factors as the differences in effluent standards and costs of capital, economies of size, and the subsidy effect are sufficient to counterbalance the quality effect.

Thus, it appears that the subsidy program does have an impact on industrial decisions concerning pollution abatement. To illustrate this impact better, a direct comparison of the costs to industry of municipal treatment before (table 15) and after (table 20) the introduction of the subsidy and cost recovery requirements can be made. The net effect of the subsidy and the accompanying cost recovery requirement is a reduction in the costs to industry of municipal treatment. These findings support the proposition that to require industry to pay back these subsidized capital costs at a zero interest rate is equivalent to subsidizing industrial wastewater treatment expenditures (7).

This analysis quantifies the impact of the subsidy program upon poultry processors. Program requirements can result in cost savings for most processors except in a few cases where small processing plants are located in very small communities. There appears to be a generally positive relationship between the cost savings and facility size (in terms of residential population served or size of processing plant served). The savings are also generally larger for inplant tertiary and land treatment systems than for secondary treatment systems. These findings are expected since the degree of capitalization is higher for these systems.

INTERDEPENDENCE OF JOINT WASTEWATER TREATMENT DECISIONS

The analysis presented thus far assumes that the community requires the firms to pay the equivalent of the average costs of joint treatment. Given this assumption, it has been possible to demonstrate the impact of joint treatment opportunities upon the independent decision frameworks of the communities and poultry processing plant located in those communities. In a previous discussion, though, it was shown that these decision frameworks are interrelated; a firm's decision concerning participation in a municipal treatment system can have an impact upon the community's objectives, and the community's policies concerning industrial participation can affect the level of such participation. It is therefore likely that, barring prohibitory transactions costs and/or regulatory constraints, the firm and the community will bargain for a mutually agreeable charge to the firm.

Table 21 summarizes the costs estimates of public and private secondary wastewater treatment for a mediun-size poultry processing plant and a community with a population of 10,000, and can be used to illustrate the relevant range of bargaining. For example, if both the community and the plant are planning activated sludge treatment systems and each constructs its own facility, treatment costs are 35.5 and 50.6 cents per 1,000 gallons for the community and plant, respectively. A joint treatment facility yields potential savings of 4 and 19.3 cents per 1,000 gallons, respectively, for the community and the plant.

Theoretically, though, the community could exact from the firm nearly its entire cost savings without affecting the firm's decision, and the firm could exact nearly the entire cost savings going to the community (it is assumed that the firm makes an all or nothing decision concerning joint treatment). The upper limit of the charge acceptable to the firm is the cost of private treatment, whereas the lower limit acceptable to the community is one that results in a cost to the community equal to the cost of treating only domestic wastes. 41/ The goals and relative bargaining powers of each party will determine the actual distribution of the mutual cost savings.

41/ It is assumed that the sole goal of the community decisionmakers is to minimize the costs of wastewater treatment so as to minimize the taxes or user fees collected from their constituents. These decisionmakers may, however, have other goals such as increasing employment opportunities, and may be willing to forego some cost savings from wastewater treatment in order to either attract new industries or retain existing ones.

Table 21--Average wastewater treatment costs for a medium-size poultry processing plant and a community with a population of 10,000

Treatment system	Public treatment of domestic wastes	Private treatment of processing wastes	Public treatment of joint wastes
		Cents per 1,000 gallons	
Activated sludge	35.3	50.6	31.3
Trickling filter	31.2	108.5	64.7
Lagoon	26.0	38.9	22.3

Slightly different results are found in situations where joint treatment leads to gains for one party and losses for the other. Assuming the same situation as above except that both parties plan to use trickling filter treatment, there is a potential cost savings of 43.8 cents per 1,000 gallons for the plant and a loss of 33.5 cents per 1,000 gallons to the community from joint treatment. Barring regulatory constraints, it can be assumed that the community will not enter into a joint treatment agreement unless it can be compensated for the loss. In this case, the total cost savings to the firm ($143,883 per year) are greater than the loss experienced by the community ($122,275 per year), so it is possible for the firm to compensate the community for its loss. The final distribution of the remaining savings is again determined by the relative bargaining powers of the two parties.

A third type of situation can exist in which neither party gains from joint treatment opportunities. This situation is represented by a case in which the plant plans to use lagoon treatment while the community is planning a trickling filter system. The respective cost increases for the plant and the community are 25.8 and 33.5 cents per 1,000 gallons. Thus, neither party has an incentive to enter into joint treatment arrangements unless a change of treatment technology can be negotiated.

The interdependence in the market for wastewater treatment services can have important implications in terms of the impact of various government water pollution abatement policies. For example, Federal construction subsidies have both a direct impact on a community through the level of wastewater treatment costs the community must bear and an indirect impact on the level of industrial participation. These implications can be more clearly demonstrated using the framework described above. The results of such analysis, though, again depend upon the assumptions made concerning the pricing of services to industrial users.

There is an additional constraint on the community in that, as a requirement for receiving the subsidy, it must collect from industrial users an industrial cost recovery fee plus a user charge based on the industry's share of operating and maintenance costs. It was previously assumed that the community would also collect a charge based on the industry's share of the remaining capital cost. Thus, it is necessary to add the average industrial cost recovery fee to the average local cost of joint treatment to determine the cost of joint treatment to industry. The results of these calculations for a medium-size poultry processing plant located in a community with a population of 10,000 are presented in table 22 for the three types of secondary treatment technologies. Examination of these results and comparisons with table 21 show that, even with the industrial cost recovery requirements, the potential cost savings for the plant are larger with the subsidy than without it.

Table 22--Average wastewater treatment costs for a medium-size poultry processing plant and a community with a population of 10,000 when the community receives a 75-percent Federal construction subsidy

Treatment system	Public treatment of domestic wastes	Private treatment of processing wastes	Joint treatment when plant pays ICR plus average local cost 1/		Joint treatment when plant pays minimum legal charge 2/	
			Community	Plant	Community	Plant
	Cents per 1,000 gallons					
Activated sludge	22.3	50.6	19.5	25.9	23.1	22.0
Trickling filter	20.7	108.5	53.1	59.4	56.6	55.5
Lagoon	16.3	38.9	13.5	19.0	16.1	16.1

1/ ICR refers to industrial cost recovery, and in this case is based on the proportion of total flow that originates from the processing plant. Average local cost refers to the unsubsidized portion of average total cost.

2/ Industrial sources are required to pay an industrial cost recovery fee plus their proportional share of operating and maintenance costs.

As described in the previous section, it is possible that the firm and the community will bargain in order to determine the actual user fees charged. Again, the upper limit of these fees acceptable to the plant is determined by the cost of private treatment. The corresponding lower limit acceptable to the community is one that results in a cost to the community equal to the average local cost of treating only domestic wastes. This lower limit, though, is further constrained to be no lower than that which is required by law; the community must, at a minimum, require payment of an industrial cost recovery fee plus a fee equal to the firm's share of operating and maintenance costs. Table 22 shows both the lower limits just described and the resulting costs to the community. Comparison of the latter to the costs of treating only domestic wastes reveals that the community will not enter into joint treatment facilities using activated sludge or trickling filters if the firm pays the minimum legal charge. The resulting costs for the community with these types of treatment are greater than the costs of treating domestic wastes.

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APPENDIX A--GLOSSARY OF TERMS AND ABBREVIATIONS

Activated sludge: a form of secondary wastewater treatment utilizing a suspended microbial growth to metabolize biodegradable wastes. See appendix B for more detailed description.

BOD (biochemical oxygen demand): the quantity of dissolved oxygen required for the aerobic decomposition of organic matter in water.

Breakeven distance: the distance between the poultry processing plant and the municipal wastewater treatment system that equates the costs to the plant of public and private treatment of its wastewater.

CAPDET (computer-assisted procedure for the design and evaluation of wastewater treatment systems): computerized simulation model developed by the U.S. Army Corps of Engineers to design and evaluate wastewater treatment systems.

Center-pivot irrigation: a mobile sprinkling system used in spray irrigation of wastewater effluent.

CLAW (cost of land application of wastewater): computer simulation model developed to design and evaluate alternative land treatment systems for wastewater effluent.

COD (chemical oxygen demand): amount of oxygen required for both biological and nonbiological decomposition of matter in water.

Effluent: the liquid portion of wastewater that has undergone treatment.

End-of-pipe treatment: that treatment of a plant's wastewater from the various production processes prior to final discharge to the environment or municipal treatment system and not including production process modifications to reduce wastes.

EPA: U.S. Environmental Protection Agency.

Evisceration: the process of removing the head, feet, and internal organs from poultry.

Fluming: the use of water to transport offal and feathers away from the processing area.

Forced-main transmission: transport of water using pumps to maintain the rate of flow.

Gravity-flow transmission: transport of water using natural forces to maintain the rate of flow.

Incompatible wastes: wastewater containing pollutants that are not normally treated by conventional biological processes. Such pollutants may interfere with the operation of or may simply pass through conventional treatment processes.

ICR (industrial cost recovery): fees used to recover from industrial contributors that portion of subsidized construction costs attributable to the treatment of their wastes.

Influent: the wastewater entering a treatment process or system.

Inplant removal: all processes, including plant modifications and end-of-pipe treatment, performed by an industrial plant to reduce the flow of quantity of pollutants discharged to the environment or municipal treatment system.

Inplant treatment: wastewater treatment occurring in a private or public treatment facility as opposed to other treatment alternatives such as land treatment, artificial aeration, and low flow augmentation.

Joint treatment: treatment of combined wastewater from domestic and industrial sources.

Kjeldahl nitrogen: the total amount of nitrogen in both ammonia and organic forms in wastewater.

Land treatment: application of wastewater effluent on land for the purpose of nutrient removal. See appendix B for more detailed description.

Lqiuid line: in terms of the CAPDET model, the series of treatment processes of a treatment train or system designed to handle the flow of wastewater through the treatment facility.

Local treatment costs: the portion of total wastewater treatment costs for which the local community is responsible; they are exclusive of Government subsidies.

Mgd: million gallons per day.

Mg/l: milligrams per liter; a measure of concentration of materials in water.

NPDES (national pollutant discharge elimination system): a system of permits to discharge wastewater to navigable waters as provided in P.L. 92-500.

Offal: the inedible parts of poultry, including head, feet, and certain internal organs, removed during evisceration.

Pass-through: the discharge of a pollutant from a treatment facility without sufficient modification or removal.

P.L. 92-500: Federal Water Pollution Control Act Amendments of 1972; provides legal framework for EPA water pollution abatement policies.

P.L. 95-217: Clean Water Act of 1977, updates and amends P.L. 92-500.

POTW (publicly-owned treatment works): a wastewater treatment facility owned and operated by a municipal authority or other public agency.

Poultry processing: as used in this analysis, the slaughtering, evisceration, and packing of young chickens.

Pretreatment: control measures and practices for wastewater from industrial sources prior to introduction into the joint treatment facility.

Primary treatment: a stage in the wastewater treatment process primarily aimed at suspended solids removal. See appendix B for more detailed description.

Quality effect: the impact on average wastewater treatment costs of varying influent quality due to industrial participation in a joint treatment facility.

Quantity effect: the impact on average wastewater treatment costs of varying influent flow due to industrial participation in joint treatment facility.

Residuals: wastes and byproducts for which the marginal costs of recovery exceed the marginal returns from recovery.

Secondary treatment: a stage in the wastewater treatment process aimed at removal of dissolved organic matter. See appendix B for more detailed description.

Sludge: the settled solids that accumulate during wastewater treatment.

Solid-set irrigation: a stationary sprinkling system used in spray irrigation of wastewater effluent.

Surcharge: fees that apply to wastewater characteristics in excess of a prespecified normal concentration.

Tertiary treatment: a stage in the wastewater treatment process primarily concerned with nutrient removal. See appendix B for more detailed description.

Threshold effect: the discontinuous impact on the operation and costs of trickling-filter systems when a certain level of BOD influent concentration is reached.

Treatment processes: as used in the CAPDET model, unit processes or combinations of unit processes frequently used together to treat wastewater.

Treatment train: as used in the CAPDET model, any feasible combination of treatment processes specified in a particular treatment scheme that constitutes a viable treatment system.

Trickling filter: a form of secondary wastewater treatment used to metabolize biodegradable wastes through continuous recycling of wastewater over microbial growth attached to a fixed medium. See appendix B for more detailed description.

User charge: fees placed on any of the characteristics, such as flow or BOD and suspended solids concentrations, of the wastewater contributed by a user of the treatment facility.

Wastewater: the influent mixture of water and waste that has not yet received treatment.

Wastewater treatment: the process by which the various components of a wastewater stream are removed and/or altered such that the remaining products (effluent and sludge) may be disposed of within relevant economic, legal, and environmental constraints.

APPENDIX B--WASTEWATER TREATMENT ALTERNATIVES

Wastewater treatment alternatives are presented according to the general categories in which they may fall: preliminary, primary, secondary, and inplant tertiary or advanced treatment (23, 25, 29). Land application is most often considered a form of advanced wastewater treatment, but it will be dealt with separately to emphasize the characteristics that distinguish it from other forms of advanced treatment. A final section will discuss the most common sludge-handling techniques.

Preliminary Treatment

Preliminary treatment prepares the wastewater influent stream for the more advanced treatment methods that follow. Several objectives may be met in this preparation process. First, large floating objects, such as rags or sticks that may clog pipes and pumps, are removed. Metal screens and/or a grinding device, known as a comminutor, may be employed for this purpose. Next, a grit chamber is used to settle out sand, grit, and small stones that are not subject to other forms of treatment. If the influent stream is highly variable in terms of flow or quality, equalization chambers, which store incoming wastewater and release it at more uniform rates, may be utilized to improve the efficiency of secondary and tertiary processes. These chambers can improve efficiency by either increasing the effectiveness of existing equipment or reducing the size and cost of new equipment.

Primary Treatment

The major objective of primary treatment is the removal of suspended solids. Three major common procedures for suspended solid removal are sedimentation, dissolved air flotation, and chemical coagulation. In a sedimentation tank, suspended solids are allowed to gradually sink to the bottom where they are removed by mechanical scrapers.

Grease and oils that may float to the top can be collected by a skimming system. Air flotation is primarily used to remove grease and fine suspended solids with a specific gravity close to that of water. A supersaturated solution of wastewater and air is created through pressurization. When the pressure is released, air bubbles effect the flotation of the suspended matter. Finally, chemical coagulants, such as alum, lime, and ferric chloride, may be used to increase the rate at which suspended solids settle. They cause the solids to coagulate and clump together, thereby causing them to settle out faster.

Another objective of primary treatment may be neutralization of the wastewater; the pH of the wastewater is adjusted to levels that will not interfere with secondary and tertiary treatment processes.

Secondary Treatment

Secondary treatment largely aims at removing the dissolved organic matter in the wastewater. Some forms of physical-chemical and land treatment processes can achieve secondary treatment standards, but the most common treatment methods are biological in nature. The latter methods include activated sludge, trickling filters, and sewage oxidation ponds or lagoons.

The incoming primary effluent in activated sludge systems is mixed with a suspended microbial growth (called activated sludge). Air and oxygen are used to stir the mixture and to provide oxygen needed for the metabolization of the biodegradable wastes. After several hours of aeration, the mixture is sent to a sedimentation tank for clarification. A portion of the settled sludge is recycled to the aeration tank to be used as a catalyst, and the remainder is transported to sludge-handling processes.

There are several variations of the conventional activated-sludge system. Step aeration activated sludge allows the introduction of wastewater flow at several points along the aeration tank, thereby spreading the oxygen demand more evenly and increasing the efficient use of oxygen. The spreading of the oxygen demand in complete mix systems is performed as uniformly as possible. Contact stabilization activated sludge permits just enough time for the microbes to adsorb the organic material. The sludge is then immediately separated and sent to another smaller aeration tank for further metabolization. An advantage to this variation is the smaller size equipment that can be utilized. The extended aeration form of activated sludge treatment permits a more complete metabolization and, therefore, eliminates the need for some sludge digestion capacity. Pure oxygen systems, as their name suggests, utilize oxygen as a substitute for air. They provide improved treatment and require smaller aeration tanks.

Trickling filters also use microbial growths; in this case, the growth is not suspended, but is attached to a fixed medium such as rocks or a synthetic material. The primary effluent is repeatedly recycled over the fixed medium allowing the organic material in the effluent to be metabolized. The resulting flow is clarified in a sedimentation basin.

The major advantages of trickling filters relative to activated sludge are their simplicity and lower energy requirements. Activated sludge requires more guarded management, but it can produce a higher quality effluent with a wider variety of influent characteristics than trickling filters because contact time is longer. In addition, trickling filters are much more sensitive to temperature changes. Finally, trickling filters are higher in capital costs and require more land area.

Anaerobic, aerated, and aerobic lagoons, the most common types, may be used separately or in series. Anaerobic lagoons are relatively deep (10 to 15 feet) with a low surface area. Treatment occurs as anaerobic micro-organisms convert organic wastes into intermediate compounds which, in turn, are converted to carbon dioxide and methane by bacteria. Anaerobic lagoons provide high removal of BOD and suspended solids at very low power, land, and management costs relative to other lagoon systems. The major disadvantage is the potential for odor problems.

Aerated lagoons are also relatively deep, but are artifically aerated. They are fairly efficient in reducing BOD, but not suspended solids. While requiring relatively low land expenditures, power requirements are substantial compared to aerobic lagoons.

Aerobic lagoons, or oxidation ponds, are engineered ponds several feet deep in which the organic material in the wastewater is metabolized under natural processes. They provide a high level of BOD and suspended solids removal with relatively low construction and power costs. Their major disadvantages lie in their dependency on weather conditions and relatively large land requirements due to the greater surface area to volume ratio they require.

Inplant Tertiary Treatment

The primary concern in tertiary or advanced wastewater treatment is the removal of pollutants, such as nitrogen, phosphorous, soluble COD, and heavy metals. These substances are only incidentally handled in secondary treatment processes. Both inplant (biological and physical-chemical) and land treatment methods are utilized in advanced treatment, but emphasis in this section will be with the former.

Chemical coagulation is the primary method of phosphorous removal. Chemicals such as lime, alum, or ferric salts, are used to precipitate suspended substances such as phosphate salts. When used in conjunction with biological secondary treatment, coagulation can also provide removal of remaining solids, heavy metals, and pathogenic organisms. The major disadvantage of coagulation is the generation of large quantities of sludge.

Nitrogen is also a critical nutrient in promoting algae growth in waterways. Biological treatment usually converts the nitrogen in wastewater to ammonia, which is oxygen consuming and toxic to some fish forms. Both biological and physical-chemical methods are employed to reduce the ammonia in the effluent. Nitrification is the biological conversion of nitrogen compounds to nitrates. This conversion can be accomplished either during normal secondary treatment or in separate treatment processes. The nitrified effluent can be either discharged or further treated for removal of the nitrates depending upon desired effluent quality. Denitrification is an anaerobic biological conversion of the nitrates to nitrogen gas. Nitrification-denitrification can remove up to 90 percent of the nitrogen with few side effects in terms of air and water quality and quantity of added sludge, but is very sensitive to toxic substances.

There are three common physical-chemical methods of ammonia removal; ammonia stripping, ion exchange, and breakpoint chlorination. In ammonia stripping, the pH of the wastewater is raised to permit conversion of the ammonium ion to free ammonia gas. The gas is then released, or stripped, by passing the wastewater through a tower having a counter current of air. This is the least-cost method of ammonia removal, but it requires large amounts of air, often results in a direct discharge of ammonia to the atmosphere, and is highly sensitive to temperature changes. During ion exchange, regeneration with salt and/or lime brine exchanges the sodium of calcium ion for the ammonium ion. This method is highly efficient in removing nitrogen (95 percent) and permits easy recycling of the nitrogen, but is rather complex and costly in terms of capital requirements. Breakpoint chlorination involves adding a sufficient amount of chlorine to the wastewater to oxidize the ammonia to nitrogen gas which is then released to the atmosphere. This process requires large quantities of chlorine, but is highly efficient and requires relatively small capital expenditures.

Soluble organic materials not removed by primary or secondary treatment processes may be removed by carbon adsorption. Activated carbon is used to adsor› both biodegradable and nonbiodegradable organic material. The latter is sometimes responsible for coloration of the effluent. This method is highly efficient and requires little space.

Filtration may remove additional suspended solids and phosphorous from secondary and chemically coagulated effluent. Conventional filtration is achieved by passing the wastewater through beds of granular material, including sand, coal, and garnet. Microscreening, another form of filtration, utilizes mechanical filters.

The removal or destruction of pathogenic organisms is referred to as disinfection. Chlorination is the most commonly used form of disinfection and is usually the final step in the treatment process.

Land Application

The application of wastewater effluent on land produces a very high level of removal for most nutrients. Treatment occurs as the wastewater interacts with the plants, soil, and organisms in the soil. The moisture and nutrients, especially nitrogen and phosphorous, can be utilized in crop production. Thus, the effluent can be considered a resource to be recycled rather than a waste to be disposed of. Preapplication treatment can consist of primary and/or secondary treatment, but usually involves some form of secondary treatment. Three general types of land application systems discussed here are irrigation, infiltration-percolation, and overland flow. Others include subsurface leach fields, deep-well injection, and evaporation ponds.

Irrigation involves the application of wastewater to land by spraying or surface spreading in order to support plant growth and to treat the wastewater. It is the most reliable and widely used of the three systems. Treatment of the wastewater involves physical, chemical, and biological means and usually occurs in the first 2 to 4 feet of the soil with removals of 20 to 90 percent for BOD, suspended solids, and bacteria, and 90 percent for nitrogen if the crop is harvested. Three methods of irrigation include spray, ridge and furrow, and flooding. The actual method used depends upon soil conditions, crop selection, topography, climate, and economics.

In infiltration-percolation systems, wastewater is applied to the soil by spreading in basins or by spraying and is treated as it travels through the soil matrix. The major objective is usually groundwater recharge rather than crop production. While it is the least costly alternative, it is also environmentally the least reliable. The wastewater usually requires pretreatment to secondary treatment quality.

Overland flow techniques involve applying the wastewater on upper reaches of sloped terraces of relatively impermeable soils and allowing it to flow across a vegetated surface to runoff collection ditches. This alternative has been used to provide secondary treatment quality to high-strength food processing wastewater. Preapplication treatment usually includes removal of large solids, grit, and grease.

In general, land application can provide high levels of treatment with little consumption of additional resources, such as chemicals and carbon, and no generation of additional sludges. The major problems involve the relatively large land requirements and public acceptance.

Sludge-Handling Techniques

Sludge produced during primary and secondary treatment activities requires additional treatment prior to disposal. The processes involving sludge treatment and disposal may be categorized into the following: sludge conditioning, thickening, stabilization, dewatering, and final disposal.

Sludge Conditioning

The primary purpose of sludge conditioning is to facilitate the separation of water from the sludge. It can also be used to alter the sludge chemically, to disinfect the sludge, to destroy odors, and to degrade some of the volatile material in the sludge. Chemical conditioning is commonly used to break down the gelatinous nature of sludge such that the solid matter and boundwater can be more easily separated. Vacuum filters and filter aides, including diatromite, fly ash, and incinerated sludge ash, have also been used to separate solids. Heat conditioning and freezing are alternative methods to aid in allowing entrapped water to be separated from the colloidal gel structure.

Sludge Thickening

After conditioning, sludge thickening is utilized to remove water from the sludge so as to reduce the volume to be handled during further treatment. Three methods generally used include gravity thickening, flotation, and centrifugation. Gravity thickening is simply a settling process that permits separation of the solids and water. While less complex, this method is not as effective as the others. In the flotation method, air-saturated clear water is mixed with the sludge; as the pressure is released, air bubbles float to the top carrying the sludge particles. Centrifugation is primarily used for dewatering of stabilized sludge but it has been used for thickening also.

Sludge Stabilization

Sludge stabilization is performed to reduce the detrimental impact of sludge disposal activities other than incineration. Several objectives may include: stabilizing the volatile portion of the sludge to prevent rapid decomposition with its resulting rapid oxygen consumption and creation of odors; altering toxicants to prevent environmental damage; and destroying pathogenic bacteria and viruses. Three general forms of stabilization are biological, chemical, and physical.

Biological stabilization involves either anaerobic or aerobic digestion of the sludge. Anaerobic digestion is the biological decomposition of organic sludge under anaerobic conditions and usually occurs in heated, enclosed tanks. This method is highly sensitive to oxygen, heavy metals, and low temperatures. In aerobic digestion, the sludge is aerated in an uncovered, unheated tank. It is less costly, in terms of money and time than anaerobic digestion, and is less sensitive to temperature changes. A variation of aerobic digestion is composting. During composting, aerobic digestion converts the organic material into a potential soil conditioner. This process results in a reduction by 50 percent of the moisture content and destruction of most pathogens.

There are two principal methods of chemical stabilization of sludge: lime treatment and chlorination. In the former, lime is used to raise the pH of the sludge which results in complex changes in the volatile solid matter, expecially when dewatered. The dewatered sludge can then be applied to land, and a gradual decomposition with less odors results. During chlorination, large quantities of chlorine are added to the sludge, and the mix is stored in pressurized tanks. The results are generally the same as with lime treatment.

Heat treatment is the most common physical stabilization method. Heating the sludge to very high temperatures (350°F to 400°F) destroys the pathogens and reduces a large portion of the volatile solids. The resulting sludge can be dewatered and applied to land or be land filled.

Sludge Dewatering

Sludge dewatering involves a further reduction in the moisture content of sludges. It allows the solids to be more economically and readily disposed of in an environmentally acceptable manner. Methods include sandbeds, vacuum filtration, and centrifugation.

Final Disposal

The final disposal of sludge can occur through ocean dumping, incinerating, landfilling, and land spreading. Ocean dumping has been widely used along coastal areas, but its adverse environmental impacts have led to Federal regulations restricting its use. Incineration reduces the mass of the dewatered sludge to less than 10 percent of its original size. The resulting ash may then be landfilled. Its advantages include a reduced volume to handle and dispose of, plus reduced ordor and pathogenic problems. Potential problems include percolation of the leachate from ash landfill and air pollution from the incineration

Landfilling is the controlled burial of waste beneath an earth cover. Partially dewatered sludge may be buried or may be mixed with solid wastes and then buried. Areas of major concern include the availability of sufficient land, control of runoff, percolation of the leachate into groundwaters, and odor and pathogenic problems.

Either liquid or dried stabilized sludge may be applied to land. The application rate suitable for a particular disposal site depends on the chemical characteristics of the sludge and the properties of the soil. Sludges high in nitrates and phosphates are less desirable, since these nutrients may reach the groundwater. In addition, high levels of trace elements, such as zinc, copper, and nickel, may be toxic to plants, while cadmium is also phytotoxic and potentially hazardous to the food chain. The chemical and physical properties of the soil partially determine the availability of heavy metals for plant uptake, movement of phosphates and nitrates through the soil, and soil erodibility and drainage.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-310-945/ESCS-86

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C. 20250

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