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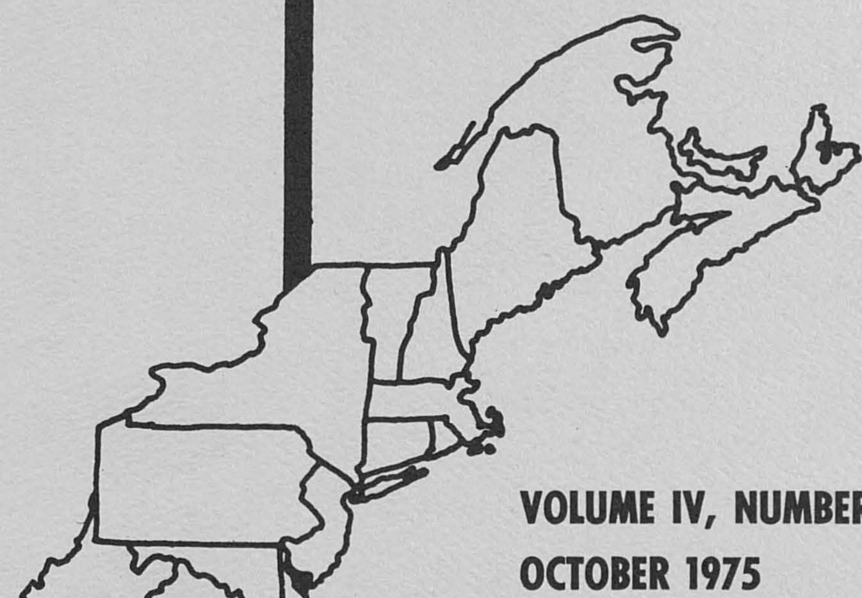

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COMPARATIVE COSTS OF MUNICIPAL WASTEWATER TREATMENT

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Higher levels of treatment of municipal wastewaters are being required by law. The 1972 Water Pollution Control Act Amendments (P.L. 92-500) established the goal of zero discharge of pollutants into the nation's waters by 1985. To meet this goal municipalities will have to build additional wastewater treatment facilities at immense cost.

While there have been numerous studies of wastewater treatment costs, most of these are engineering studies which assume treatment systems that use inputs in fixed proportions.[1/] These studies present results for each treatment process using exponential cost functions. Engineering studies conclude that average costs decrease as the flow of wastewater increases and that they increase as the level of treatment increases. Simple regression analysis is used; thus, relative price variations, different treatment levels and influent characteristics, and varying degrees of capacity utilization are not included. Inclusion of a capacity utilization variable in a study of wastewater treatment costs may provide a significant improvement in light of the recent study by Urban Systems Research and Engineering [7]. They found that sewage collection facilities are being designed much larger than they need be to serve existing and anticipated populations, which may also be true of sewage treatment facilities. This paper proposes to examine the cost structure of municipal wastewater treatment using regression analysis. An additional variable, capacity utilization, will be included in the cost function.

Economic Model

A cost model for municipal wastewater treatment has been developed by Young and Carlson [9]. The present analysis will use their model. Output is measured as a joint product of the rate of wastewater flow (Q_1) and the level of treatment (Q_2). Assuming that the production function is an exponential function[2/] and that facility operators use the

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[1/] See Tihansky [6] for a comprehensive review of the cost literature.

[2/] Most empirical studies of wastewater treatment cost functions use exponential cost functions.

efficiency criterion (the marginal value products per dollar for each input are equal), the cost function for wastewater treatment can be written as:

$$C = \alpha_0 Q_1^{\alpha_1} Q_2^{\alpha_2} S^{\alpha_3} P_L^{\alpha_4} P_K^{\alpha_5} P_F^{\alpha_6} \qquad (1)$$

where C = annual operating and construction costs

Q_1 = average daily flow of wastewater

Q_2 = final effluent concentration

S = size or capacity utilization variable

P_L = price of labor

P_K = annual price of capital

P_F = price of fuel

α_{0-6} = coefficients to be estimated.

The coefficients from the cost function (equation 1) can be interpreted individually. Since the cost function is derived in the form of a power function, the coefficients can be interpreted as cost elasticities. When output, either flow (Q_1) or treatment level (Q_2), increases, annual costs are expected to rise. Thus, the coefficient α_1 is expected to be positive, while α_2 will be negative, since an increased level of treatment will be reflected as a decrease in the final concentration of the effluent. A second hypothesis can be tested regarding the coefficient of flow. If there are economies of plant size in wastewater treatment, the coefficient, α_1, will be less than one.

The relative size or capacity utilization variable (S) is included in the analysis to center the discussion on long run costs. This variable permits comparisons of facilities which use different proportions of their capacity while providing an estimate of the cost of reserve flow capacity. Specifying the capacity parameter as the average proportion of flow capacity presently utilized, the coefficient (α_3) is expected to be negative. As the proportion of capacity utilized increases, long run costs fall. The effects of reserve capacity may differ between secondary and advanced treatment. Reserve capacity is determined by expected population growth, daily peak flows, the initial cost of capital, the difficulty of obtaining capital funds, and the length of time required to make additions to capital facilities.

In addition to the interest costs of reserve capacity, operating costs also increase due to increased energy and labor requirements to operate and maintain larger treatment units. The Environmental Protection Agency [2] estimated that $670 million of excess sewage treatment capacity existed in 1968, which resulted in approximately $22.5 million of extra annual operating and maintenance costs. They assumed that the rate of growth in facility use would be 25 percent. While only those plants operating at less than 80 percent of designed capacity were defined by the EPA as having excess capacity, this study considers all unused capacity as reserve capacity.

Treatment plants capable of handling larger than average flows of wastes are needed to handle flow variations and population growth. Sewage flow will vary throughout the day and throughout the year. For instance, water usage increases during the summer for clothes cleaning, baths, and certain industrial operations. Also, if infiltration occurs or if the storm drainage system is connected to the sewer system, wastewater flows will increase during periods of rainfall. As a community grows additional treatment capacity is needed. Since there are economies of scale in construction and capital acquisition, treatment plants need to be built large enough to handle future population growth. Optimal size is determined by the marginal cost of constructing the extra plant capacity originally [3/] versus the marginal cost of future additions to plant capacity. Unfortunately this anslysis will not be able to address the question of construction timing due to a lack of data.

The remaining variables in equation 1 are factor prices which are expected to be positively associated with annual costs.

Empirical Analysis

To apply the cost model, 500 cities in the southern half of the United States (from Maryland to California) were surveyed in 1973 to obtain data on wastewater treatment costs. One hundred and twenty five cities responded. The problem of bias in sampling due to higher response rates from larger plants was corrected by stratifying the sample by size, and following mail questionnaires with telephone requests to all respondents. The sample distribution was very similar to the parent population.

Both questionnaire responses and secondary data sources were used to compile measures for each treatment facility. Municipal sewage officials supplied data [10] on annual costs (C), treatment volume (Q_1), level of treatment (Q_2), and proportion of capacity used (S). Treatment volume was measured in average million gallons treated per day.

3/ The extra operating and maintenance costs associated with larger plants should be included in the cost analysis.

The level of treatment was measured as BOD concentration (mg/l) when the effluent leaves the plant. The proportion of capacity used (S) was measured as average million gallons treated per day divided by designed capacity in million gallons per day.

Price data were obtained from secondary sources. Labor prices (P_L) utilized were average county skilled worker wage rates [8]. A composite price of capital (P_K) was developed using the local interest rate and regional construction costs [3, 10]. Regional electric rates in dollars per 750 killowatt hours [4] were used as the price of fuel (P_F).

The parameters of equation 1 were estimated for three sets of circumstances with log-linear multiple regression. The cost function was estimated for all levels of treatment, for those plants with less than 90 percent BOD removal (primary and secondary treatment), and for those facilities achieving greater than or equal to 90 percent BOD removal (advanced treatment). Comparison of the parameter estimates between equations will provide information on the effect of requiring advanced wastewater treatment on treatment costs. Total costs were measured as the annual expenditures made by the municipality for wastewater treatment [10], exclusive of collection costs. Engineering data were used to estimate the life expectancies of the various capital assets. The life expectancies ranged up to 30 years for concrete and steel structures [10].

Table 1 gives the parameter estimates for the three regressions.[4/] The variables explain over 75 percent of the variation in costs. All of the coefficients have the expected sign. For the "all treatment" regression all of the coefficients except for the price of electricity are significantly different from zero at the .05 or lower levels. The constant and the coefficient of flow are significant at the .01 level for the primary and secondary treatment regression while the capacity utilization variable is significant at the .1 level. All of the coefficients in the advanced treatment regression are significant at the .1 or lower level.

[4/] The cost equations were estimated from cross-sectional survey data. When cross-sectional data are used, a tendency for the error term to be heteroscedastic (i.e., a non-constant variance) exists. A test to determine if the data exhibit heteroscedasticity was made by plotting the estimated residuals against the predicted values of the dependent variables for each of the regressions. No systematic increase in scatter occurred; therefore, heteroscedasticity was assumed not to exist.

Table 1
Estimation of Annual Municipal Wastewater Treatment Costs[a/]

Variable (Natural Logarithms)		All Treatment	Primary & Secondary Treatment[b/]	Advanced Treatment[c/]
Constant	α_0	7.7533*** (5.0217)	10.1153*** (4.6820)	4.3511** (2.1278)
Q_1 Flow (mgd)	α_1	0.8304*** (18.8529)	0.8968*** (15.8338)	0.7073*** (9.9579)
Q_2 Treatment level (mg/1 of BOD)	α_2	-0.1478** (-2.1597)	-0.1527 (-1.1593)	-0.3077* (-1.6630)
S Proportion of capacity utilized	α_3	-0.3465** (-2.2952)	-0.2982* (-1.3024)	-0.5018*** (-2.8594)
P_L Price of labor	α_4	0.6664*** (2.4417)	0.4141 (1.0114)	1.1658*** (3.3617)
P_K Price of capital (interest and construction cost)	α_5	0.4144** (1.8249)	0.2260 (0.6964)	0.7674*** (2.7063)
P_F Price of electricity ($/750 KWH)	α_6	0.2362 (0.5236)	0.5144 (0.7608)	0.9846** (1.8218)
R^2		0.7818	0.7608	0.7505
Sample size		125	73	52

a/ Values in parenthesis are t values for tests of significance from zero.

b/ <90% BOD removal

c/ ≥90% BOD removal

*,**,*** denote significance at .10, .05, and .01 levels, respectively, with a one-tailed test.

The average flow of wastewater significantly affects wastewater treatment costs. All of the coefficients of flow are significantly greater than zero at the .1 level. A 10 percent increase in flow will cause treatment costs to increase by 8.30 percent, 8.97 percent and 7.07 percent for the "all treatment," primary and secondary treatment, and advanced treatment regressions respectively. The hypothesis of economies of size was tested by computing t values for the coefficients being less than one. The calculated t values are -3.8545, -1.8233, and -4.1225 for "all treatment," primary and secondary, and advanced treatment, respectively. Each of the coefficients is significantly less than one at the .1 or lower levels of significance. It is interesting to note that economies of scale are greater for advanced waste treatment than for primary and secondary treatment. Since annual costs for advanced treatment will increase by 7.07 percent with a 10 percent increase in flow, an incentive exists for consolidating the area served. To examine this question fully, collection costs need to be added to treatment costs.[5/]

The coefficient of treatment level (α_2) was significantly different from zero for the "all treatment" and advanced treatment regressions. A 10 percent decrease in final effluent quality (i.e. an increase in the level of treatment) will cause costs to increase by 1.5 to 3.1 percent depending upon the current level of treatment. The coefficient of treatment level for the advanced treatment regression is almost twice as large as the same coefficient for primary and secondary treatment. This implies that the incremental costs of achieving higher levels of treatment as required by P.L. 92-500 will require substantial investments.

Reserve treatment plant capacity significantly affects total annual costs. Each of the capacity utilization coefficients is significantly different from zero at the .1 or lower level. A 10 percent increase in capacity utilization will result in a 2.98 percent decrease in costs for primary and secondary treatment plants while "all treatment" plant costs will fall by 3.46 percent. Again, the importance of the variable is evident when advanced treatment is considered. In this case a 10 percent increase in capacity utilization will cause a 5.02 percent decrease in annual costs.[6/] As treatment plants are required to go to higher levels of treatment, planners have an additional

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[5/] See [5] for a discussion of the influence of collection costs on optimal plant size.

[6/] Note that this coefficient is significant at the .01 level.

incentive to make accurate population and flow projections to reduce the average reserve capacity over the life of the facility. Techniques and facilities for reducing flow variations should be considered. Storage facilities can be constructed for raw or partially treated wastewaters. This appears to be attractive where there are wide seasonal variations in surface receiving waters. Variable surcharges on industrial discharges can be introduced. Elliott and Seagraves [1] found that a 10 percent increase in sewer rates will result in a 10 percent decrease in industrial waste discharges. Treatment techniques such as chemical coagulation which use relatively more variable inputs can be utilized to reduce the amount of idle capacity. Given the preliminary evidence on capacity costs developed in this analysis, the influence of the above alternatives on treatment costs need to be evaluated.

All of the price coefficients for advanced treatment were significantly greater than zero at the .05 level, while none of the price coefficients for the primary and secondary treatment regression were significant. The coefficients of the prices of labor and capital were significant for the "all treatment" regression.

The interesting comparison for the price coefficients is between the advanced treatment regression and the other two. Advanced treatment costs are more sensitive to price changes than lower levels of treatment. A 10 percent increase in labor prices will cause a greater than 10 percent increase (11.66 percent) in costs for advanced treatment, while costs will increase by less than 10 percent (6.66 and 4.14 percent) for the other regressions. An increase in the price of capital will result in almost double the percent increase in costs for advanced treatment (7.67 percent versus 4.14 and 2.26 percent). The coefficient of the price of electricity was significantly greater than zero for the advanced treatment regression. In this time of rising energy prices it is interesting that a 10 percent increase in energy costs will generate a 9.85 percent increase in advanced treatment costs. The high cost-price elasticities for advanced treatment may be due to the precise nature of the technology. Few substitutes exist for the factors of production used in advanced wastewater treatment.

Conclusions

Wastewater treatment cost functions have been estimated using multiple regression analysis. Three types of cost functions were estimated: all levels of treatment, primary and secondary treatment, and advanced treatment. Cross-sectional survey data for communities in the southern half of the United States were used. The advantage of this analysis over previous estimates of wastewater treatment costs is the use of multiple regression. Multiple regression analysis permits variations in flow, treatment level, input prices, and the degree of capacity utilization to be incorporated in the analysis.

Four conclusions for wastewater treatment follow from this analysis. All of the estimated coefficients had the hypothesized signs. (1) The average flow of wastewater through a treatment facility significantly affects annual costs for all levels of treatment. (2) There are economies of scale in wastewater treatment. The coefficient of flow is significantly less than one for each of the equations. The significance level for the advanced treatment and "all treatment" regressions was .01, while for primary and secondary treatment it was .1. (3) The level of treatment, measured as final BOD concentration, influenced treatment costs, especially at high levels of treatment. Input prices were found to affect wastewater treatment costs for the "all treatment" and the advanced treatment regressions. (4) The most important feature of this analysis was the inclusion of a capacity utilization variable in the cost function. Previous estimates of wastewater treatment cost functions have not included this type of variable. The variable was found to affect treatment costs significantly. Planners have an additional incentive to make accurate population and flow projections to reduce the average reserve capacity over the life of the facility. To determine the optimal amount of reserve capacity a model utilizing population and flow projections, financing options, desired industrial growth, and future environmental requirements would be needed.

Comparison of the parameter estimates between equations provided information on the effect of requiring advanced wastewater treatment on treatment costs. Economies of scale from increasing the flow of wastewater through the treatment facility are greatest for advanced wastewater treatment but were also exhibited in the case of primary and secondary treatment. This implies that municipalities should consider consolidated treatment facilities whenever collection costs permit. A percentage increase in the level of treatment will cause advanced treatment costs to increase twice as much as primary and/or secondary treatment costs. Reserve capacity imposes a greater penalty on annual costs for advanced treatment. Advanced treatment costs are more sensitive to relative price changes than lower levels of treatment. The cost-price elasticities of labor and electricity are approximately one for advanced treatment and the cost price-elasticity of capital is .77. As energy prices continue to rise, planners should be aware of their impact on wastewater treatment costs.

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