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Economic Analysis of Wastewater Treatment Alternatives

IN RURAL TEXAS COMMUNITIES

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ECONOMIC ANALYSIS OF WASTEWATER TREATMENT ALTERNATIVES IN RURAL TEXAS COMMUNITIES

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SUMMARY

Growing rural communities face pressure to provide services to their populations. Wastewater treatment represents one of the many services in which communities must invest. The choice of an appropriate treatment facility represents a major decision and hinges on such factors as technical feasibility, cost, and treatment effectiveness so that there is compliance with the water quality standards embodied in the Clean Water Act. The focus of this study is analysis of investment, operation, and maintenance costs of sewage treatment plants. Average per capita sewage flow rates are determined for communities of less than 10,000 inhabitants throughout Texas. Additionally, design sizes for various types of plants are estimated from models developed here. Capital, operation, and maintenance costs are estimated on an annual basis for several types of treatment plants. The analysis reveals that sewage systems demonstrate economies of size across capital, operation, and maintenance costs.

Keywords: wastewater, rural communities, costs, treatment plants.

INTRODUCTION

Public concern for the quality of water discharged into the nation's waterways contributed to the passage of legislation known as the Federal Water Pollution Control Act of 1972 (FWPCA). The provisions of the FWPCA established a goal of zero discharge of pollutants into navigable waterways and set requirements that communities strive to develop the "best practicable treatment technology" including reclamation and recycling through the production of agricultural crops. The law authorized federal funding of up to 75% of construction costs to engender investment in improved wastewater treatment facilities.

In response to delays in compliance with the law, Congress passed amendments to the FWPCA. These amendments, known as the Clean Water Act, reemphasized the need to improve discharge water quality standards and created further incentives for the development of alternative and innovative technologies such as land application of effluent. These incentives included:

1. An increase in the federal share of funding for construction from 75% to 85% of total construction costs.
2. Public funding for alternative systems even when these systems are not the most effective. Funding is permitted where the discrepancies in life cycle costs of the alternative treatment works and the most cost effective treatment works do not exceed 15%.

Under the provisions of the Clean Water Act, communities are obligated to improve the quality of effluent emanating from their wastewater plants through either the upgrading of facilities, the construction of new facilities, or the adoption of efficient alternative technologies. Owing to the fiscal incentives for construction, the communities are responsible for funding only between 15% and 25% of the construction costs. However, they are responsible for funding the entire cost of operation and maintenance. Therefore, even though a system may appear attractive due to low initial costs, its attractiveness may prove short-lived once operation and maintenance costs are considered.

The fiscal incentives provide an impetus for small-community investment in sewage treatment facilities. Further impetus is provided as communities seek to comply with federal regulations and to deliver needed public services. This dual goal of compliance and service provision represents a major undertaking for a community. Complications arise as each community attempts to select the system that best meets its needs in terms of cost and treatment effectiveness; they often lack access to the information necessary to make the choice. Community leaders should therefore consider the various alternative systems when making an investment decision.

DESCRIPTION OF TREATMENT ALTERNATIVES

Several types of secondary treatment plants [1] are available to rural communities. Except for very small communities which still utilize individual treatment methods such as septic tanks, municipalities treat wastes through centralized systems. Several alternative treatment methods are

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[1] Secondary treatment is defined as reduction in the five-day Biological Oxygen Demand (BOD) effluent concentration to between 25 and 30 mg/1 (U.S. Environmental Protection Agency, 1978).

available for selection by communities, but only the most popular systems are surveyed here.

Nonmechanical Systems

Imhoff tanks are community-wide septic tank prototypes. Many communities in Texas utilize imhoff tanks due to their relative low capital and operation and maintenance costs (O&M). For many years, they have served community treatment needs, but recently communities have begun to abandon them in favor of other systems. Their rising unpopularity stems from the odor emitted during the treatment process and the availability of equally efficient and inexpensive alternatives which produce little or no odor.

Another nonmechanical treatment system which provides low-cost treatment is the facultative lagoon or waste stabilization pond. Where land is plentiful, lagoons offer an attractive alternative due to their relatively low operation and maintenance costs and reasonable capital costs. Goldstein and Moberg have shown that per capita costs for both capital and maintenance are lower for stabilization ponds and lagoons than for other prevalent systems. Per capita annual maintenance costs, in 1982 dollars, ranged from $5.72 for a community of 500, $2.91 for one of 1,000, and only $2.18 for a larger town of 2,000 inhabitants. Capital costs exhibited similar economies of size, as per capita costs ranged from $348.74, $131.72, and $86.60, respectively (Goldstein and Moberg). Generally, land costs represent the greatest capital cost component while labor costs dominate O&M expenditures.

Mechanical Systems

Mechanical systems are also common in rural Texas. These systems are expensive to construct, operate, and maintain and require skilled operators to ensure their efficient functioning. Costs of labor, energy inputs, chemicals, and repairs are much higher for these types of systems than for lagoons or stabilization ponds. One of the least expensive mechanical, or semi-mechanical, systems is the aerated lagoon. Aerated lagoons resemble facultative ponds except that they employ an aerator for treatment purposes. The popularity of both facultative and aerated lagoons has increased greatly over the past several years in Texas. Aerated lagoon systems are preferred over simple lagoon systems in those areas where land is scarce.

Other popular mechanical systems include oxidation ditches, which are widely used in Texas, and activated sludge plants. Goldstein and Moberg collected both per capita capital and O&M data for activated sludge plants. In 1982 dollars, per capita capital costs for lagoons were $444.10 for communities of 200 inhabitants, $278.83 for populations of 1,000, and where population reached 2,000, $236.72. The respective per capita operation and maintenance costs were $25.00, $17.00, and $14.38.

Jones also reported economies of size for operation and maintenance costs for treatment plants with flows between 0.25 and 2.0 million gallons per day (MGD) in Ontario, Canada. Tchobangolous obtained similar results when he surveyed systems throughout the United States with daily flows between 0.05 and 1.0 MGD.

Sundry cost studies of sewage treatment facilities have been prepared by the Environmental Protection Agency to assist planners in their efforts to furnish their communities with cost-effective treatment works (February, 1981). In its technical report on construction costs for municipal treatment plants, the EPA develops cost curves from construction bid data available from regional offices throughout the United States with facility capacities between 0.02 and 300.0 MGD. Operation and maintenace costs for the period from 1973 to 1981 were also evaluated by the EPA (September, 1981). The agency's study on O&M costs focused on expenditures related to the daily operation and maintenance that occur for both plants and conveyance systems with capacities between 1.0 and 100.0 MGD offering at least secondary treatment. The report presents a very detailed cost study; cost curves are derived from systems and components on a national and regional level and offer useful cost estimations that may help communities avoid system closure due to inadequate funding in the future.

OBJECTIVES

This study addresses rural community investment in wastewater treatment facilities with the goal of providing information that may assist communities in selecting the most appropriate wastewater treatment system. Specific objectives established to meet this end are:

1. Estimation of sewage flow a plant is likely to receive on a daily, monthly, and annual basis.
2. Development of models which estimate capital costs for the most commonly found systems.
3. Development of models which estimate operation and maintenance costs for the most commonly found systems.
4. Examination of land application of wastewater effluent as an alternative to traditional wastewater treatment methods.

THE DATA

The amount of sewage flow is important in determining design size of a wastewater treatment facility. Design size is the significant factor in the assessment of both investment and annual costs. The analysis of municipal treatment systems involved the determination of rates of sewage flow and costs incurred in constructing, operating, and maintaining sewage treatment plants for rural Texas communities with populations of 10,000 or less. Flow and cost estimates are obtained from regression techniques applied to the various data collected for sewage flow and community expenditures.

Sewage Flow, Rainfall, and Population

Data on sewage flow, annual rainfall, and population for rural communities in Texas with daily rates of sewage flow less than 1.5 million gallons per day (MGD) were assembled for the various communities. The sewage flow data were obtained from the records of the Texas Department of Water Resources in Austin (TDWR). Annual rainfall for the 503 communities was obtained from the National Climate Center's *Annual Survey of Climatological Data for Texas, 1981.* Population data were available from the 1980 Census data.

Two sewage flow parameters were available for each community, average daily and maximum daily flows for each month for the years 1980 and 1981. Average daily flow was selected over maximum daily flow due to completeness of the data. Furthermore, it was felt that the average daily flow would be subject to less variation and thus provide a more realistic view of the quantity of sewage flow available.

Capital Cost

Capital cost data for 60 systems were collected from the files of TDWR. For each system, cost information was gathered for the plant structure, engineering and contingency fees, and initial collection system costs. However, only the cost of the treatment plant structure was considered in the regression. Collection system costs were not included in the analysis as they should be the same regardless of the type of treatment plant adopted. The 60 systems were separated by type into 19 oxidation ditches (racetracks), 19 activated sludge plants (primarily contact stabilization plants), 6 aerated lagoons, and 16 which were either imhoff tank/waste stabilization pond systems or facultative lagoons.

Operation and Maintenance Cost

The collection of operation and maintenance (O&M) cost data proved a more difficult task. The vast majority of the communities combined their sewer budgets within either the general municipal budgets or else within their water budgets. The often-used rule of thumb whereby 40% of a combined water and sewer budget is designated to sewer costs and the remaining 60% to water could not be employed in this study; more specific information was needed.

Some O&M costs were procured from telephone conversations throughout the state. Additionally, questionnaires were sent to the 503 communities for which flow data were available.

Of the 140 questionnaires that were returned, 75 contained information sufficiently complete to construct the sample. The sample size is small; however, the EPA (September, 1981) reports that in a national survey of operation and maintenance costs for wastewater plants, costs for only 60% of the systems could be acquired due to poor record keeping. The EPA study attributed the poor data reporting to smaller communities with fewer than 5,000 inhabitants, the size of communities which dominate the observations for this analysis. For each observation, costs were divided into those for labor, fuel and utilities, repairs, chemicals, administration, and miscellaneous expenses. These costs were summed to determine total annual costs in 1982 dollars.

Plant design sizes were not available from the budgets reviewed, nor were they solicited in the questionnaires. Therefore, design sizes were estimated using a regression equation derived for design size as a function of population for those systems for which capital cost data were available. Population figures for the communities in the O&M sample were inserted into the equation and design sizes obtained. These generated design sizes would then be used in the regression equation for the dependent variable explaining total operation and maintenance costs. As a final step in the analysis of O&M costs, per capita costs were determined and comparisons made across several plant types.

THE ANALYSIS

Estimating Sewage Flow

To satisfy the first objectives of this research effort, it was necessary to identify potential relationships existing between annual average sewage flow, population, and rainfall. Regression analysis was employed to specify such relationships. The following equation represents a best fit equation of all functional forms tested:

$$(1) \qquad \text{Flow} = .0076\ \underset{(42.67)}{\text{pop}^{1.05}}\ \underset{(2.67)}{\text{rain}^{.22}} \qquad R^2 = .78$$

where:

Flow = estimated sewage flow in million gallons per year:
pop = population;
rain = annual rainfall in inches; and
numbers in parentheses = the t values for the beta coefficients.

The beta coefficients from the population and rain variables are both significant at the 95% level.

This model can be used to estimate annual flow, and thereby both daily average and daily per capita flow. For example, suppose a community in Texas has a population of 1,000 and an average rainfall of 36 inches. The average annual flow can be determined by inserting these values into equation (1) as follows:

$$\text{Flow} = .0076\ (1000)^{1.05}\ (36)^{.22}$$

Estimated annual flow would be 23.62 million gallons per year (MGY), average daily flow would be 64,712 gallons per day (GPD), while per capita flow would be approximately 64.71 GPD.

These figures provide the planner with an average value for flow, but disregard system peak requirements, generally considered to be 1.2 times the average daily flow (International Reference Centre, 1981). In the case mentioned above, multiplying average daily flow by 1.2 would yield 77,655 GPD as a peak requirement. This peak flow figure is useful in designing plant size since peak demand must be met to ensure the efficient operation of the treatment plant.

Table 1 provides a list of average daily, average peak, and per capita daily flow rates for hypothetical communities with varying populations and annual rainfalls of 20, 36, 50 inches. Note that as population grows, per capita flow rates tend to increase. This increase could be attributed to the fact that as a community grows, more stores or hotels may be constructed, a hospital may be erected, or other sources of nonhousehold sewage flow such as industry may come into existence. Also notice that as rainfall increases, sewage flow increases due to infiltration in the collection system.

Estimating Capital Costs

Equations were developed to identify the relationship between design flows and population and to indicate capital costs of secondary wastewater treatment plants as a function of design size. To determine the necessary plant size and costs the following relationships were estimated.

Table 1. Average Flows for Several Population and Rainfall Scenarios in Gallons per Day.

	FLOW (RAIN = 20)			FLOW (RAIN = 36)			FLOW (RAIN) = 50		
Pop	Average Daily	Average Peak	Per Capita	Average Daily	Average Peak	Per Capita	Average Daily	Average Peak	Per Capita
500	27,457	32,949	54.9	31,248	37,498	62.5	33,590	40,308	67.2
1,000	56,852	68,223	56.9	64,700	77,641	64.7	69,549	83,459	69.5
1,500	87,025	104,430	58.0	99,038	118,846	66.0	106,461	127,753	71.0
2,000	117,714	141,126	58.9	133,964	160,757	67.0	144,004	172,805	72.0
3,000	180,187	216,224	60.1	205,061	246,074	68.4	220,430	264,516	73.5
5,000	308,081	369,698	61.6	350.611	420,733	70.1	376,888	482,266	75.4
7,000	438,631	526,358	62.7	499,183	599,020	71.3	536,596	643,915	76.7
10,000	637,892	765,470	63.8	725,951	871,141	72.6	780,358	936,430	78.0

(2) size = c pop $^{\beta}$ and

(3) icost = k size $^{\beta}$

where:

size = treatment plant design in MGD;
pop = population; and
icost = cost of treatment plant in 1982 dollars.

The general models were estimated first for all systems. The treatment plants were then separated by type and analyzed. Results of these regression procedures are shown in Table 2. It is noteworthy that the exponents on all forms of equation 2 are significant at the .05 level or greater and that in all instances they are less than one, indicating economies of size. That is, both in terms of size and costs, the functional relationships related to population are increasing at a decreasing rate. This may be demonstrated by substituting various values of population and size to estimate design size and construction.

Estimating Operation and Maintenance Costs

Models similar to those estimated for capital costs were developed for operation and maintenance costs. The general model is specified as follows:

(4) omcost = m size $^{\beta}$

where:

omcost = cost of operation and maintenance in 1982 dollars; and
size = treatment plant design in MGD.

Six individual specifications were evaluated and the resultant estimated equations are shown in Table 2 at the bottom. Equation T9 represents the regression equation for the 75 systems for which the most reliable data were available and for which the design size variables were generated, while equation T11 shows the estimated equation using EPA data. Equation T10 is representative of the eight observations for which actual design size data were available. Finally, equations T12 through T14 represent equations derived for racetrack, lagoon and activated sludge systems, respectively.

Unlike the equations estimated for capital construction costs, only three of the six equations indicate that economies of size may be present. The EPA study shows that O&M costs are increasing at a decreasing rate, indicating economies of size. However, for both equations which used aggregated data gathered in this study, the coefficients on the size variable exceeded one. In the case of equation T9 with 75 observations, the coefficient is 1.05, while for equation T10 with only 8 observations, the coefficient rose to 1.26. Thus, this study indicates that costs increase at an increasing rate as design size is enlarged in the small community classification.

When the data are disaggregated, economies of size can be observed for both the racetrack and lagoon systems. The coefficients on the size variables in equation T12 and T13 are 0.76 and 0.77, respectively, indicating that average costs increase at a diminishing rate as design size increases. The coefficient on the size variable in equation T14 for activated sludge plants is 1.22.

TABLE 2. SUMMARY OF PLANT DESIGN SIZE, PLANT CONSTRUCTION COST ESTIMATION, AND OPERATION AND MAINTENANCE COST, BY SYSTEM TYPE

System Type	Equation	t-Value of β Coefficient	R^2	N
Design Size Estimation[a]	Size			
T 1) All Systems	$.0007\ pop^{.801}$	10.48	.65	60
T 2) Oxidation Ditches	$.00199\ pop^{.701}$	4.80	.58	19
T 3) Lagoons	$.0086\ pop^{.737}$	3.20	.42	16
T 4) Activated Sludge	$.0006\ pop^{.826}$	9.40	.84	19
Construction Cost Estimation[b]				
	Cost			
T 5) All Systems	$1{,}199{,}000\ size^{.509}$	8.13	.53	60
T 6) Oxidation Ditches	$1{,}077{,}000\ size^{.523}$	4.40	.53	19
T 7) Lagoons	$734{,}000\ size^{.339}$	2.32	.28	16
T 8) Activated Sludge	$1{,}867{,}000\ size^{.640}$	7.00	.74	19
Operation and Maintenance Cost Estimation[c]				
	Cost			
T 9) All Systems, Design Size Generated	$122{,}103\ size^{1.05}$	11.09	.63	75
T10) All Systems, Design Size Available	$167{,}000\ size^{1.26}$	4.90	.80	8
T11) All Systems, EPA Data	$66{,}860\ size^{.826}$	—	.86	37
T12) Racetrack Systems Only	$92{,}967\ size^{.76}$	4.30	.40	28
T13) Lagoon Systems Only	$44{,}356\ size^{.77}$	2.47	.30	16
T14) Activated Sludge Systems Only	$185{,}350\ size^{1.22}$	7.18	.76	18

[a] Dependent variable is treatment plant design in million gallons per day (MGD).

[b] Dependent variable is capital cost (investment) of treatment plant in 1982 dollars.

[c] Dependent variable is annual O&M costs in 1982 dollars.

Total Annual Costs

Total annual costs for treatment plant alternatives are shown in Table 3. Costs are presented in total per capita, community share per capita, and total community terms. Only 25% of construction costs are included in the community per capita figure due to the 75% EPA grant rate on these costs. Total community costs reflect the actual annual expenditures incurred for the treatment system. As anticipated, activated sludge systems are shown to be most costly with lagoon systems being least costly. Note in particular the differences in O&M costs under each alternative. Goldstein and Moberg reported average per capita costs for activated sludge plants at $19.58 which is quite close to results obtained for Texas. They also reported average per capita O&M costs for waste stabilization ponds. Their value of $3.60 corresponds to the values obtained for Texas and suggests similarity of costs for different areas in the United States. The Goldstein and Moberg values do not include administrative costs, whereas this study does.

While the per capita figures reflect that considerable cost differences exist between system types, the potential impact of these differences may not be fully realized until they are presented as total annual community costs. The results in Table 3 indicate that annual costs for activated sludge, racetrack, and lagoon treatment systems for a community of 5,000 are $151,700, $99,900, and $38,000, respectively. Cursory inspection of these data reflects sizable potential savings dependent upon system type. (This assumes that there are no effluents which require the more specialized disposal techniques achieved by these mechanical activated sludge and racetrack plants in comparison to lagoon systems.) Certainly a reduction in annual expenditures of up to $113,700 would have a substantial impact on the fiscal situation of a community of 5,000.

LAND APPLICATION

Land application of municipal effluent as a form of treatment and a means of supplemental irrigation represents an apparently viable and valuable alternative to the previously described wastewater treatment systems for communities wishing to comply with the FWPCA while avoiding the higher construction and O&M costs of traditional wastewater treatment and disposal methods. To date, over 125 Texas communities are employing some form of land application of effluent as part of the treatment process. Land application offers many economic advantages, especially if effluent use for irrigation is considered. While this section of the study does not provide an economic analysis, it is used to present advantages and disadvantages of land application and relate findings from previous research which may prove useful in the decision to utilize this alternative for wastewater treatment.

Advantages and Disadvantages

Municipalities can benefit from land application through lower operation and maintenance costs, as most communities utilizing this alternative need only lagoons rather than more costly mechanical systems. Because the soil acts as a biological filter providing for efficient removal of the pollutants contained in residential wastewater, communities can eliminate advanced levels of treatment in most instances. Where land treatment is employed, primary treatment may be all that is required; the soil acts as a secondary and tertiary filtering system. Benefits for the farmer result from an assured source of water and nutrients contained in the effluent which are applied to crops. Advantages can be summarized as follows:

1. Potential increased municipal water supplies resulting from decreased groundwater water usage for agricultural purposes. A trading system would need to be developed

TABLE 3. TOTAL ANNUAL PER CAPITA AND COMMUNITY TREATMENT PLANT COSTS FOR POPULATIONS OF 5,000 AND 10,000

System Type	5,000 Population			10,000 Population		
	Total per capita[a]	Community per capita[b]	Total community[c]	Total per capita	Community per capita	Total community
			Dollars			
Racetrack						
Construction	18.43	4.60	23,000	11.90	2.97	29,700
O&M	15.38	15.38	76,900	11.13	11.13	111,300
TOTAL	33.81	19.98	99,900	23.03	14.10	141,000
Lagoon						
Construction	10.98	2.74	13,700	6.53	1.63	16,300
O&M	4.86	4.86	24,300	3.60	3.60	36,000
TOTAL	15.84	7.60	38,000	10.13	5.23	52,300
Activated Sludge						
Construction	28.54	7.12	35,600	20.55	5.13	51,300
O&M	23.22	23.22	116,100	23.34	23.34	233,400
TOTAL	51.76	30.34	151,700	43.89	28.47	284,700

[a] Includes all annual O&M costs and all capital costs amortized at 9% over 30 years.

[b] Includes all annual O&M costs and 25% of all capital costs amortized at 9% over 30 years.

[c] Total estimated costs for entire population of the community.

with farmers for their irrigation water.

2. Recharging of groundwater through application for irrigation.

3. Provision of revenue to the community from the sale of effluent or from land leasing arrangements made with farmers to utilize effluent for agricultural production. Revenue from these arrangements can be used to offset the cost of system operation and maintenance.

4. Provision of water to areas where the agricultural base depends upon irrigation and where the cost of using groundwater is high.

5. Recycling of nutrients which are needed to produce high crop yields. Fertilizer costs for farmers may be reduced through use of the nitrogen, phosphorous, and potassium contained in the effluent (Gravitz et al.)

Land application has many advantages, but it must not be considered as a panacea for either municipal wastewater disposal problems or farm irrigation requirements. In many areas land treatment is not feasible or appropriate. Land treatment could require purchases of large tracts of land by the community, resulting in high initial investment costs. Complex arrangements with farmers for distribution and utilization of the effluent would be required. The city must ensure that the farmer either uses the effluent or provides sufficient storage for it during nonirrigation times to prevent overflow of untreated wastes onto bordering lands or into rivers and streams.

The community must prevent contamination of solids and groundwater. In small communities, the major problem would involve groundwater contamination from leached salts (Thomas and Law; Ellis et al.). Municipalities must be particularly aware of the various forms of nitrogen in wastes -- their properties and various transformations in soils -- to implement application and cropping strategies that result in the maintenance of permissible levels of nitrogen in groundwater (Loehr et al.). It is unlikely that smaller communities would need to concern themselves with toxic wastes or heavy metals using either primary or secondary treated effluent. The amount of such elements are present in concentrations below contaminant standards and are usually concentrated in sludge.

Findings of Previous Research

Numerous studies have been conducted over the past decade to investigate the economic and biological aspects of land application of effluent. Such research has considered land application from the community and the producer levels. The material presented below will highlight research focusing on the community level. A more detailed investigation of the literature in land application may be found in Victurine.

Malhorta and Myers studied communities in Michigan of fewer than 10,000 inhabitants, the majority of which utilized slow rate application of wastes for agricultural purposes. In a comparison of treatment effectiveness, they discovered that land treatment provided equal or better treatment of wastes than most conventional tertiary treatment facilities, the effluent infiltrating the groundwater did not adversely affect water quality, and operation and maintenance costs for the land application systems were significantly lower.

Malhorta and Myers' discovery that operation and maintenance costs were lower for systems using land application rather than conventional systems are similar to results obtained by other researchers (Crites and Pound; Reed and Buzzel; Loehr et al.; Cantrell et al.; Young). Malhorta and Myers studied communities which needed to either upgrade an existing plant or install a completely new system. For newly installed systems the operation and maintenance, as well as the overall costs, were much lower for those using land treatment. Capital costs for the land treatment systems were higher if the community chose to purchase land needed for treatment rather than lease land or sell effluent for irrigation purposes. Cost savings were also obtained when the land treatment and conventional waste systems were compared for communities wishing to upgrade existing facilities. The savings did not approach the level of those obtained for the newly installed systems and in some cases the differences were negligible.

A study by Young determined that annual costs of land application systems proved lower for facilities with daily flows ranging between 0.5 and 2.5 MGD. Capital costs accounted for 80% of total costs, while O&M costs represented 20%. These figures compare to a 50% division between capital and O&M costs for advanced wastewater treatment (AWT) systems. This cost difference is significant since communities are responsible for financing 100% of O&M costs whereas their construction costs are grant eligible.

Reed and Buzzel also reported significantly lower O&M costs for land application systems. In studies done in Michigan and Pennsylvania, energy utilization and costs per MGD were measured for both AWT and land treatment systems. Energy utilization and thus the cost of energy for AWT systems with capacities between 1.0 and 2.0 MGD surpassed those same costs for land treatment systems six- to eightfold. Since energy costs represent one of the major O&M expenses, significant cost savings would accrue to a land treatment system.

In many cases, land application systems cost more to operate than necessary. EPA studies show that many systems provide secondary treatment when such treatment is not absolutely required. Presently, primary treated effluent can be used to flood or furrow-irrigate feed crops or fiber crops, such as corn for cattle feed, pastureland, and cotton. Only a minority of systems which irrigated these crops with effluent utilized primary treated effluent. Graviz considers secondary treatment of effluent for nonfood crop irrigation "unnecessarily cautious, expensive, and wasteful of nutrients you are trying to recycle." Cantrell et al. report, however, that where irrigation is done with sprinklers, secondary treatment will be necessary to remove solids which may clog nozzles. Sutherland and Myers believe that the most cost-effective alternative for pretreatment in land application systems is the waste stabilization pond. Effluents from these ponds can be used in most types of irrigation systems. Where land is available in adequate quantities and at acceptable prices, ponds provide a relatively inexpensive form of treatment.

CONCLUSIONS AND LIMITATIONS

The models developed for determination of sewage flow and capital and annual costs could prove useful in assisting rural community leaders in their decisionmaking processes with regard to investment in wastewater plants. The capability of determining flow allows communities to design for appropriate-sized plants, thus avoiding overdesign and unnecessary costs. Over design causes increases not only in investment costs, but also in O&M costs since the plant must operate whether flows through it are of design capacity or smaller.

The analysis of costs of treatment systems demonstrates that both lagoon-stabilization pond systems and oxidation ditches enjoy economies of size for both construction and O&M costs. Therefore, any growth of demand on these systems will result in lower per unit costs. These lower costs are especially important in small rural communities whose populations are often growing slowly, if at all. Communities need a sufficient resource base to cover costs of operating and maintaining their systems, since all O&M costs must be paid by the community from its budget.

A community should also consider the waste disposal method which provides the necessary treatment quantity at the lowest possible cost. This study indicates that lagoons are the least expensive method of treatment for rural communities, and should be seriously considered where land is available in adequate quantities.

In areas where land is not abundant or is expensive, oxidation ditch systems represent a relatively economical alternative. When choosing to invest in a mechanical system such as an oxidation ditch, communities should ensure that plant operators are well trained so that costly repairs and excessive down-time can be avoided. Rural wastewater treatment should stress simplicity in design, operation, and maintenance to ensure adequate and reliable service at a cost which can be comfortably met by consumers.

Land application offers the benefits of system cost savings, revenue earning capacities, and nutrient provision to crops. Moreover, land application represents an excellent treatment method that the EPA considers better than can be achieved with a typical activated sludge plant. Despite the benefits, costs do exist. Thomas and Law, Ellis et al., and other researchers have noted increased levels of nitrogen in the soil and groundwater. Although the evaluation of nitrate contamination is beyond the scope of this report, it should not be overlooked, especially considering the increased attention given to the problem in literature. The focus of much recent research is the introduction of cropping systems that allow high nitrogen utilization. Presently, forage crops appear to be the preferred crops.

The limitations of this study result from difficulty in obtaining data on specific treatment system costs and some very basic constraints on research time and resources. Operation and maintenance costs were particularly difficult to acquire due to poor records kept by small communities. Hence, only a small sample size could be analyzed. An increased sample size could be obtained if larger communities (up to 25,000) were incorporated into the study.

Another problem was that sample sizes for obtaining construction and other initial costs were relatively small, especially when the data were disaggregated by system type. Paucity of construction cost data and the research time limitations in searching resulted in samples of collection system costs being obtained. This study examines only the costs of the various treatment plants and does not address the costs of collection systems. This is unfortunate since collection system costs generally represent the largest portion of total sewage system investment costs.

Despite the limitations of the study, it provides important information to rural communities that face uncertain growth rates and are constrained both in planning expertise and fiscal resources. When properly used, this information could prove invaluable in direction, planning, operating, and maintaining the most appropriate wastewater treatment alternative based on functional characteristics and economic considerations.

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