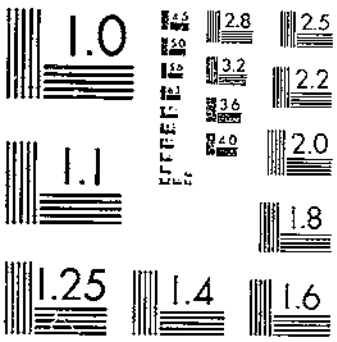
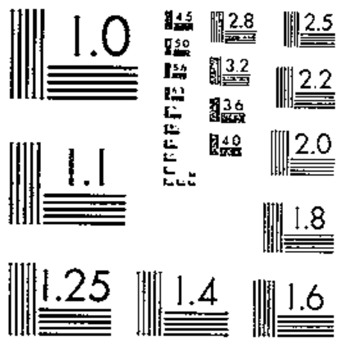
TB 1594 (1978) USDA TECHNICAL BULLETINS UPDATA
LAND APPLICATION OF WASTEWATER A COST ANALYSIS
YOUNG, C.E. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LAND APPLICATION OF WASTEWATER: A COST ANALYSIS

C. Edwin Young

U.S. Department of Agriculture

Economics, Statistics, and Cooperatives Service

Technical Bulletin No. 1594

LAND APPLICATION OF WASTEWATER: A COST ANALYSIS. By C. Edwin Young, Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture. Technical Bulletin No. 1594.

ABSTRACT

Land application of wastewater is a cost effective method for advanced wastewater treatment. Compared with conventional advanced wastewater treatment technologies, land application is less expensive for facilities treating less than 5 million gallons of wastewater per day. Crop selection exerts the greatest influence on costs through a crop's impact on the application rate, the length of the irrigation season, and crop revenues. Other factors analyzed include land costs, effluent transmission, public health constraints, storage, and the application rate.

Keywords: Wastewater, Land treatment of wastewater, Costs, Cost effectiveness, Simulation, Municipal sewage.

ACKNOWLEDGMENTS

Appreciation goes to Lee Christensen of the Economics, Statistics, and Cooperatives Service and Don Epp of The Pennsylvania State University for assistance in the planning and execution of this study. The author extends appreciation to the Institute for Research on Land and Water Resources, The Pennsylvania State University, for its services and assistance to the project.

Washington, D.C. 20250 September 1978

EDITOR'S NOTE

This bulletin follows a 1976 work by C. Edwin Young titled The Cost of Land Application of Wastewater: A Simulation Analysis (TB-1555). It is available from ESCS publications, 0054-S, U.S. Department of Agriculture, Washington, D.C. 20250. The following is abstracted from that bulletin:

> Land treatment of wastewater is a cost effective method for advanced treatment of municipal sewage. Costs of land treatment of wastewater are analyzed using a computer simulation model. Six alternative techniques for land application are examined. Variations in costs are studied using cost estimates and cost elasticity estimates. Assuming that the soil requirements are met, infiltration basins are the least cost technique for land application. Center pivot irrigation is the least cost irrigation alternative examined. Analysis of treatment economies of size indicates that most of the advantages to increasing facility size have been realized after facility size reaches 10 million gallons per day.

CONTENTS

SUMMARY

Land application is often a cost effective method for advanced wastewater treatment, especially for smaller communities which generate less than 5 million gallons of wastewater per day. The relative cost effectiveness of land application decreases as facility size increases since land application is subject to fewer economies of size than the conventional advanced wastewater treatment technologies examined.

Crop selection was found to have the largest impact on land application costs. In addition to revenues from crop sales, certain crops such as reed canarygrass are capable of being irrigated at higher application rates and for longer irrigation seasons. This can significantly reduce costs. Chlorination is a cost effective method for limiting public health hazards. Buffer zones may also be cost effective, especially if land prices are low or the buffers can be farmed thus producing a revenue to offset treatment costs. Buffers also provide an area for future expansion of the land application system. Although land costs do not exert as large an influence as might be anticipated, communities can further reduce their costs by pumping the wastes to more distant sites which may be less expensive.

Communities may be induced to select lower application rates if construction subsidies are available. With subsidies, local treatment costs may be lower at the lower application rate. This provides some excess treatment capacity for the community, since when community growth occurs, the application rate can be increased for nominal increases in operation and maintenance costs.

LAND APPLICATION OF WASTEWATER: A COST ANALYSIS

by

C. Edwin Young
Agricultural Economist

INTRODUCTION

The cost effectiveness of land application of wastewater is evaluated in this analysis. Land application refers to the controlled discharge of partially treated sewage effluents onto land to remove contaminants from the water. The soil and vegetation adsorb and filter the contaminants. Recycling wastewater through land application has been shown to provide a high degree of wastewater treatment (5).[1/]

The 1972 Amendments to the Water Pollution Control Act (P.L. 92-500) call for upgrading the level of wastewater treatment throughout the United States and encourage the recycling and reuse of wastewaters whenever possible. The Clean Water Act of 1977 (P.L. 95-217) states that:

> . . . the Administrator [of the Environmental Protection Agency] shall not make grants . . . [for wastewater] treatment works unless the grant applicant has satisfactorily demonstrated to the Administrator that innovative and alternative wastewater treatment processes and techniques which provide for the reclaiming and reuse of water, otherwise eliminate the discharge of pollutants, and utilize recycling techniques [such as] land treatment . . . have been fully studied and evaluated by the applicant.

1/ Underlined numbers in parentheses refer to items in the references section.

The Act further provides for a grant of 85 percent rather than 75 percent of construction costs for communities utilizing innovative treatment techniques such as land treatment. 2/

In order to foster the development of land application systems, the U.S. Environmental Protection Agency (EPA) has published several documents illustrating the concept of land treatment of wastewater. Pound and Crites (8, 9) discuss the concept of land application of wastewater. Sullivan, Cohn, and Baxter (15) report on an EPA-sponsored survey of existing facilities which use land application. More than 100 municipal and industrial land application facilities were visited to determine their operational characteristics. Using mail questionnaires and bibliographic review, an additional 300 facilities were evaluated. Two technical bulletins for use in designing land application systems were published by EPA's Office of Water Program Operations. The first (3) presents the technical features associated with the design of land application systems, while the second (10) presents a methodology for estimating the costs of wastewater treatment by land application.

National and regional workshops were held in 1973 and 1974 to discuss the state of the art and research needs relating to land application of wastewater. EPA, the U.S. Department of Agriculture, and the National Association of State Universities and Land Grant Colleges sponsored a national workshop on recycling municipal sludges and effluents on land at Urbana, Illinois (7). Three regional workshops were subsequently held to assess the progress made and to plan for future research relating to land application of wastewater (6, 12, 13). Research priorities within major areas were identified at each workshop.

This bulletin follows a USDA technical bulletin on research evaluating the costs of land application of wastewater. The first report (19) developed a model for simulating land application costs, estimated treatment costs, and analyzed variations in individual cost parameters. The present analysis focuses on the relative cost effectiveness of land application as a method of advanced wastewater treatment. First, the cost effectiveness of land application is assessed by comparing the costs of land application of wastewater with conventional inplant wastewater treatment techniques. This is followed by an analysis of factors which influence the cost effectiveness analysis. Factors analyzed include: land costs, pumping distance, health considerations, the application rate, storage requirements, and crop selection. Finally, the relative importance of policy restrictions on the cost effectiveness of land application is assessed.

2/ Public Law 92-500 provides for a subsidy of up to 75 percent of the capital costs involved in construction of a waste treatment facility, while Public Law 95-217 provides an additional 10-percent subsidy for innovative treatment processes such as land application. Eligible costs include all elements which are integral parts of the waste treatment process. For land treatment this means that land which is involved in the treatment process and for storage lagoons is eligible, while land for treatment lagoons, buffer zones, and roads is not eligible. Many States provide additional subsidies for a portion of the remaining construction costs.

COST EFFECTIVENESS ANALYSIS

Cost effectiveness is assessed by comparing simulated cost estimates for land application with similar estimates for inplant advanced wastewater treatment. Simulation analysis was selected as the mode of analysis for three reasons: (1) simulation analysis permits examination of land treatment under a wide variety of scenarios, (2) the direct impact of individual parameters can be observed, and (3) since only a limited number of land application systems are being operated for advanced wastewater treatment, insufficient data are available for statistical analysis.

Cost of Land Application of Wastewater Model

Cost estimates for land treatment of wastewater are generated using the cost of land application of wastewater (CLAW) model (19). The CLAW model is based on the Pound, Crites, and Griffes (10) methodology for estimating the cost of land application of wastewater.

The CLAW model simulates five basic steps: preapplication treatment, transmission, effluent storage, application system, and recovery of renovated water. Preapplication treatment is assumed to be aerated lagoon treatment although other methods of pretreatment can be included. 3/ Effluent can be transmitted to the application site using forced main or gravity main transmission systems. The model is capable of varying the distance over which wastewater is transmitted and can account for some variations in topography. The storage function is broken into three parts. First, there is a storage function for wastewater which is normally assumed not to be applied to the ground for some portion of the year. This value can be varied at the user's discretion. Second, extra or supplemental storage capacity can be built into the cost estimates as a safety factor. Third, the model permits stream discharge of wastewater for some portion of the year when it is not being applied to the land. Application systems in the CLAW model include: solid-set crop irrigation, center-pivot crop irrigation, surface irrigation of crops, solid-set irrigation of woodland, overland flow, and infiltration basins. 4/ Finally, the model includes recovery of the renovated wastewater if needed. This option includes recovery wells, underdrains, and not recovering the effluent.

3/ Aerated lagoon pretreatment is assumed since it is generally the least cost method to obtain an adequate level of treatment prior to land application. Land application does not require high levels of pretreatment of the effluent. Alternative secondary treatment techniques are likely to be used prior to land application when the treatment authority has an existing facility in place or when additional treatment is deemed necessary for public health reasons.

4/ Surface irrigation, overland flow, and infiltration basins are not discussed in this article. Readers interested in these options are referred to (19). Many of the conclusions reached in the analysis concerning spray irrigation apply equally to the other land application techniques.

Land Application Cost Estimates

Cost estimates were prepared using the CLAW model for solid-set and center-pivot spray irrigation of wastewater (table 1). Costs for center-pivot irrigation are 2.5 to 8 cents per 1,000 gallons less than the cost of equivalent sized solid-set systems. The use of center-pivot irrigation requires a relatively flat terrain while solid-set irrigation can be used on more uneven terrains and in wooded areas. 5/ A 1-million-gallon-per-day (MGD) center-pivot irrigation system costs 63 cents per 1,000 gallons while an equivalent sized solid-set irrigation system costs 69 cents per 1000 gallons. The 63 cents per 1,000 gallon cost of the center-pivot irrigation system is composed of 53 cents per 1,000 gallons of average capital costs plus 19 cents per 1,000 gallons of average operating costs, minus 9 cents per 1,000 gallons of net crop revenue.

The operating costs associated with crop management are included in the average net crop revenue estimate rather than in the average operating cost estimate. The model assumes that there are no economies of size in crop management. Average per acre crop revenue is a constant for each cropping alternative considered. Therefore, average net crop revenue measured in cents per 1,000 gallons remains constant as facility size changes. Average net crop revenue will change when the number of acres irrigated with a fixed annual volume of wastewater changes due to variations in the application rate or the length of the irrigation season.

While average net crop revenue may exceed average operating costs for large facilities, it is unlikely that average net crop revenue will exceed the sum of average operating and average capital cost (19). If a community receives a Federal or State grant for construction of the treatment facility, 6/ it is possible for the sum of the remaining capital costs and average operating costs to be less than average net crop revenue for a given size facility. This possibility is examined in a later section.

There are definite economies of size in land treatment of wastewater. Average total costs fall from $2.30 per 1,000 gallons for a 0.1-MGD solid-set facility to 38 cents per 1,000 gallons for a 100-MGD solid-set facility, 7/ while for center-pivot irrigation they fall from $2.27 per 1,000 gallons (0.1-MGD facility) to 30 cents per 1,000 gallons (100-MGD facility). Average total costs fall rapidly as facility size increases to 5 MGD. Further increases in facility size result in relatively smaller cost decreases (falling by 10 cents per 1,000 gallons).

5/ The cost estimates presented in table 1 do not apply to spray irrigation of wooded areas. Irrigation of wooded areas requires adjustments in the assumed spacing of the irrigation risers and the net crop revenue estimates.

6/ See text footnote 2.

7/ The cost estimates for the 0.1- and 100-MGD facility sizes are the extremes of the data and are not likely to be as accurate as cost estimates for facilities in the 0.5- to 50-MGD range.

Table 1--Average cost estimates for spray irrigation of wastewater[1]

Facility size (MGD)	Average capital cost	Average operating costs[2]	Average net crop revenue[3]	Average total costs
	Cents per 1,000 gallons			
Solid-set:				
0.1	188.2	51.5	9.4	230.3
0.5	77.5	23.2	9.4	91.3
1.0	61.0	17.9	9.4	69.5
5.0	45.0	12.0	9.4	47.6
10.0	42.4	10.8	9.4	43.8
50.0	39.2	9.2	9.4	39.0
100.0	38.5	8.7	9.4	37.8
Center pivot:				
0.1	180.4	56.7	9.4	227.7
0.5	69.9	24,6	9.4	85.1
1.0	53.5	19.0	9.4	63.1
5.0	37.1	12.8	9.4	40.5
10.0	34.4	11.4	9.4	36.4
50.0	31.0	9.4	9.4	31.0
100.0	30.2	8.9	9.4	29.7

1 Assumes: average daily flow indicated, aerated lagoon pretreatment, 2 inches per week application rate, 40-week irrigation season, 14 weeks of storage capacity, distance to the land application site is 2 miles, effluent is chlorinated, sewer construction cost index is 248.7, sewage treatment plant construction cost index is 232.5, discount rate is 6 percent, discount period is 20 years, price of land is $1,500 per acre, wage rate is $6.00 per hour, price of chlorine is $0.06 per pound, electricity rate is $0.03 per kWh, the wholesale price index is 140, and the crop irrigated is corn, alfalfa, or grain sorghum using the cropping assumptions specified by (19).

2 Average operating costs do not include the operating costs associated with crop management.

3 Average net crop revenue is average gross crop revenue less the average costs associated with crop management. The crops which can be irrigated at this net revenue include corn, alfalfa, and grain sorghum (19).

Comparison with Other Wastewater Treatment Techniques

Effective evaluation of land application of wastewater requires a cost comparison with other methods of wastewater treatment. Cost estimates for two secondary treatment processes and three advanced wastewater treatment (AWT) processes are illustrated in table 2. Spray irrigation is more expensive than trickling filters or activated sludge treatment (the two secondary treatment processes) but is less expensive than three advanced wastewater treatment techniques illustrated. 8/ A 1-MGD center-pivot irrigation system is 14 cents per 1,000 gallons less costly than activated sludge treatment followed by nitrification-denitrification (AWT1), 66 cents per 1,000 gallons less than activated sludge followed by lime addition, filtration, and sludge recalcination (AWT2), and 81 cents per 1,000 gallons less than AWT2 plus ion exchange (AWT3). For a 10-MGD facility, AWT1 is 6 cents per 1,000 gallons less costly than center-pivot irrigation, while AWT2 is 15 cents per 1,000 gallons more expensive than center-pivot irrigation and AWT3 is 26 cents per 1,000 gallons more than center-pivot irrigation.

The advantages of irrigation as a method for advanced wastewater treatment are greater for smaller facilities. Examination of the relative cost differences between the AWT options and the irrigation options shows that the relative advantages of land treatment decrease and actually disappear as facility size increases (table 2). Therefore, it is likely that spray irrigation will be especially attractive to smaller communities. 9/

Cost comparisons between various treatment processes are useless unless these costs are related to the relevant effluent quality or degree of treatment provided by each process. Effluent qualities for land treatment and the advanced wastewater treatment systems are compared in table 3. AWT1 provides a degree of nitrogen removal similar to that of irrigation, AWT2 provides a similar degree of phosphorus removal to irrigation, and AWT3 provides a similar degree of wastewater treatment to irrigation. Since land treatment is less costly for small facilities than AWT1, AWT2, and AWT3 (table 2), given the assumptions of this analysis, and provides a higher degree of treatment, it can be concluded that land treatment can be a cost effective method for advanced wastewater treatment. 10/

8/ EPA (4) reports that construction costs for conventional wastewater treatment estimated using reference (16) may underestimate actual construction costs. Actual costs may be 1 to 2.5 times higher. Additionally, economies of size are less than indicated by (16). This information has not been incorporated into this analysis, since comparable information is not available for the engineering cost data in the CLAW model.

9/ It may not be possible to construct large land application systems based on the assumptions in this analysis. Systems larger than 10 MGD may have to pay considerably more than $1,500 an acre for land. They may have to pump their wastewater much farther than the assumed 2 miles. Other factors may also affect the relative cost effectiveness of larger land application facilities.

10/ All possible advanced wastewater treatment techniques are not illustrated in table 2; only representative techniques are presented.

Table 2--Comparison of average total wastewater treatment costs for various facility sizes[1]

Treatment technique	Facility size (MGD)						
	0.1	0.5	1.0	5.0	10.0	50.0	100.0
	Cents per 1,000 gallons						
Trickling filter	142.9	65.7	48.3	25.4	15.8	14.2	13.6
Activated sludge	157.1	70.0	42.4	26.4	19.1	14.8	13.6
AWT1: Activated sludge followed by nitrification-denitrification	[2]X	105.5	77.5	39.7	30.0	23.2	21.1
AWT2: Activated sludge followed by lime addition, filtration, and sludge recalcination	[2]X	165.0	129.4	70.6	51.6	35.0	31.7
AWT3: AWT2 plus ion exchange	[2]X	184.8	144.5	82.7	62.1	42.9	35.8
Solid-set irrigation	230.3	91.3	69.5	47.6	43.8	39.0	37.8
Center pivot irrigation	227.7	85.1	63.1	40.5	36.4	31.0	29.7

1 Updated cost estimates from (16) and table 1.

2 Insufficient data are available to extrapolate to this facility size. It is unlikely that smaller facilities will choose these advanced wastewater treatment techniques.

Table 3--Effluent quality comparison for land treatment and advanced wastewater treatment systems

System	Effluent quality parameters			
	Biochemical oxygen demand	Suspended solids	Total nitrogen	Phosphorus
	Mg/ℓ			
Activated sludge	20	25	30	8
Trickling filter	40	50	30	8
AWT1: Activated sludge followed by nitrification-denitrification	15	16	3	8
AWT2: Activated sludge with lime addition, filtration, sludge recalcination	5	5	30	0.5
AWT3: AWT2 plus ion exchange	5	5	3	0.5
Irrigation	1	1	3	0.1

Source: (11).

The relative cost advantage of land treatment over the AWT options is due to the use of aerated lagoon pretreatment prior to the land treatment. Aerated lagoons are an inexpensive way to provide sufficient pretreatment for wastewater prior to applying it to land, while the effluent from an aerated lagoon may not be of sufficient quality for discharge directly to a stream or as an influent to an advanced wastewater treatment system. The cost estimates for land treatment can be adjusted to account for other pretreatment techniques by adding the costs of a secondary treatment process such as trickling filter or activated sludge to the land treatment costs and deducting the costs of aerated lagoons. 11/ Substitution of activated sludge pretreatment for aerated lagoons prior to solid-set irrigation alters the relative cost effectiveness of irrigation compared to AWT. AWT1 becomes less expensive than irrigation while,

11/ Aerated lagoons cost approximately 57 cents per 1,000 gallons for a 0.1-MGD facility, 22 cents per 1,000 gallons for a 0.5-MGD facility, 13 cents per 1,000 gallons for a 1-MGD facility, 6 cents per 1,000 gallons for a 5-MGD facility and 4 cents per 1,000 gallons for larger facilities.

for facilities of 10 MGD or larger, AWT2 is less expensive. For facilities larger than 50 MGD, AWT3 is less costly.

A community with an existing secondary treatment facility may not need to use aerated lagoons for pretreatment. The community must determine if the costs of operating its existing treatment facility are greater than or less than the costs of building and operating an aerated lagoon pretreatment system minus the salvage value of the old treatment facility.

FACTORS INFLUENCING THE COST EFFECTIVENESS ANALYSIS

The analysis now turns to examination of the factors which affect the relative cost effectiveness of land treatment versus the advanced wastewater treatment techniques illustrated. Those factors affecting the cost effectiveness of both land treatment and advanced wastewater treatment are addressed briefly, followed by a detailed discussion of six items which specifically affect land treatment costs. These items include: land costs, effluent transmission distance, public health restrictions, storage requirements, the application rate, and crop selection.

Factors Affecting All Wastewater Treatment Costs

Land application has a higher ratio of capital to operating costs than the other advanced wastewater treatment alternatives under examination. Capital costs are three to four times larger than operating costs for land application (table 1) while, for the three AWT options, the ratio of capital to operating costs is approximately one to one (16). Therefore, increases in construction costs will tend to increase land treatment costs more than AWT costs while increases in operating expenses such as wages, energy, and chemicals will tend to increase AWT costs more than irrigation costs. Federal subsidies for construction of wastewater treatment facilities increase the relative cost effectiveness of land application to the local community for two reasons. First, a constant percentage subsidy for construction costs will reduce costs to the local community more for land application than for alternative treatment processes since a greater proportion of land application costs are for construction. Second, land application qualifies for an additional 10-percent construction subsidy under P.L. 95-217. These generalizations may not hold for increases in specific cost items. Insufficient data are available to analyze the AWT options in more detail.

The impact of variations in individual cost parameters for land treatment was analyzed separately (19). Variations in design flow, construction costs, discounting procedure, the wage rate, and crop prices exerted the largest impact on land treatment costs, while changes in costs of energy and chlorination have negligible impacts.

Land Costs

Land costs may not exert as large an impact on land application costs as might be anticipated. Land has a value at the end of the life of the irrigation project. Whether land appreciates or depreciates while being used as a wastewater irrigation site depends on many factors. If the system is poorly operated and the soil is depleted or poisoned from applications of toxic materials, the land may decrease in value over time. If, however, the system is well operated, soil texture may improve and thus increase the value of the land. Economic factors in the local land market will also influence whether land appreciates or depreciates over the life of the facility. The discounted value of land in the future must be deducted in a cost effective analysis. If land is assumed to have a constant value throughout the life of the irrigation project, the relevant annual land cost is the interest cost of holding the land (interest rate times land cost). EPA assumes that real land values do not change during the life of a land application facility (10). Since this appears to be a reasonable assumption for general analyses, it has been incorporated into the CLAW model. Thus, the annual cost of an acre of land initially costing $1,500 per acre with a 6-percent interest rate is $90.00 per acre. 12/ If land values are assumed to appreciate at a rate of 5 percent a year, land costs are $22.58 per acre while, if it is assumed that the land is worthless after the 20-year life of the system, land costs are $130.78 per acre. 13/

The effect of increasing initial land prices is shown in table 4. Assuming that land does not appreciate or depreciate, an increase of $1,000 per acre in the price of land results in an increase of 4 to 6.3 cents per 1,000 gallons in average total costs, depending on facility size. How much can a municipality afford to pay for land? Assuming that a 1-MGD facility has to pay $10,000 per acre for its land rather than the assumed $1,500 per acre, average total costs will increase 36 cents per 1,000 gallons to a total of 99 cents per 1,000 gallons for a center-pivot irrigation system (total derived from data in tables 2 and 4). Land treatment remains less expensive than the phosphorus removal options (AWT2 and AWT3) in table 2. AWT2 costs $1.29 per 1,000 gallons while AWT3 costs $1.44 per 1,000 gallons for a 1-MGD facility.

Effluent Transmission

A community can lower land costs by pumping the wastewater farther from the city. Craig and Mapp (2) found that average land costs decrease as the distance from an urban center increases. Costs for a 1-mile increase in the transmission distance for land treatment facilities are set forth in table 4.

12/ If the land is removed from the property tax rolls when a community purchases land for wastewater irrigation, the annual value of lost property tax revenues should be added to the estimated land costs. If the land treatment site is located outside the political jurisdiction of the treatment authority, a payment in lieu of taxes may be necessary.

13/ If land values are assumed to appreciate at a faster rate than the interest rate, rather than having an annual land cost, the system will have revenue to be deducted from the system's costs.

Table 4--Increase in average total costs for increases in land prices and transmission distance

Facility size (MGD)	Per $1,000 per acre land cost increase	Per 1 mile increase in transmission distance
	Cents per 1,000 gallons	
0.1	6.3	20.0
.5	4.5	5.0
1.0	4.2	3.3
5.0	4.0	1.4
10.0	3.9	0.9
50.0	3.8	0.4
100.0	3.8	0.2

Small facilities must pay up to 20 cents per 1,000 gallons to pump their wastes 1 additional mile, while a large 100-MGD facility pays only 0.2 cents per 1,000 gallons per mile. A 1-MGD facility can pump its wastes over 1 mile in order to obtain a $1,000 per acre decrease in land costs, while a 10-MGD facility can go almost 4 miles.

The cost estimates used thus far assume forced main effluent transmission. Significant cost savings will result if a community can use gravity transmission to its application site. A 0.1-MGD facility will save 1.8 cents per 1,000 gallons when gravity transmission is used.

Public Health Constraints

Transmission of pathogens and viruses via aerosols is a potential public health problem associated with land application of wastewater. 14/ Proposals to reduce the health hazard include: chlorination, the use of buffer zones or buffer lands surrounding the irrigation site, and additional pretreatment of the effluent prior to land application. 15/

14/ Aerosols refer to small droplets of water that float beyond the confines of the land treatment site.

15/ An additional method to reduce aerosol transmission is to alter the spray equipment. Aerosol size and the distance that the effluent is propelled into the air can be reduced, thus limiting the aerosol transmission problem. This alternative is not examined in this analysis since no cost data on the impact of alterations in the equipment are available. It should be noted that the cost estimates do include some modifications in conventional irrigation equipment. To determine the extent of these modifications refer to (10).

Effluent chlorination reduces the pathogenic and viral organisms in sewage effluent. Effluent chlorination has been used throughout the world prior to surface discharge of the effluent. Effective chlorination may be the most cost effective method of reducing pathogenic organisms in effluent for spray irrigation (14). Chlorination costs comprise less than 4 percent of the total costs for spray irrigation facilities (tables 1 and 5). Including filtration prior to chlorination increases average total costs by 5 to 25 percent (tables 1 and 5).

Buffer areas are a second major way of reducing the possibilities of pathogenic contamination from spray irrigation. A buffer area is land between the irrigation site and the general public which does not receive wastewater irrigation. Sorber (14) indicates that buffers may not provide sufficient reductions in pathogens. Buffers in excess of 330 feet produce limited aerosol reduction, making them unnecessary except for esthetic purposes.

Buffer areas can significantly increase the acreage requirements for a land application site, especially for smaller facilities. The percent of total land requirements needed for a given buffer falls substantially as facility size increases (table 6). And, as facility size increases, the impact of buffer requirements on total land requirements is lessened.

The cost of owning buffer areas can be computed in the same manner as irrigation site land costs. The cost of holding land for spray irrigation is the interest cost of the land. Land is assumed to be worth as much at the end of the facility life as it is at the beginning. Applying this logic to the acreage requirements for buffers, the cost of buffer zones can be computed. 16/ An acre of land held as a buffer adds 0.0246 cents per MGD per 1,000 gallons to average total treatment costs. Therefore, a 100-foot buffer zone around a 1-MGD facility will add less than 1 cent per 1,000 gallons to total treatment costs, while a 500-foot buffer zone will add 4 cents per 1,000 gallons. 17/ Buffer land need not sit idle. Since the irrigation site is being farmed, the buffer can also be farmed, thus providing a potential revenue which can be applied against the cost of the buffer zone. If it is assumed that the real value of land appreciates over time, the relevant costs of buffers are further reduced.

Buffer zones can be used as an area for expansion of the land application site as community wastewater treatment needs grow. As growth occurs, the community can substitute additional chlorination of the effluent for the buffer zone.

16/ The cost of an acre of land held as a buffer (0.0246 cents per MGD per 1,000 gallons) is computed by multiplying land costs ($1,500 per acre) times the interest rate (6 percent) and dividing by the number of thousands of gallons of wastewater treated annually (365,000 per MGD).

17/ The 4 cents per 1,000 gallons cost of the 500-foot buffer zone is computed by multiplying 0.0246 times 168 acres and dividing by 1 MGD.

Table 5--Average total costs for chlorination

Facility size (MGD)	Chlorination only	Filtration plus chlorination
	Cents per 1,000 gallons	
0.1	9.2	33.4
.5	3.6	19.8
1.0	2.4	16.0
5.0	1.2	9.5
10.0	1.0	7.8
50.0	0.6	4.7
100.0	0.5	3.7

Table 6--Acreage requirements for buffer zones, lagoons, and irrigation site plus buffer zones

Facility size (MGD)	Acreage required for lagoons and irrigation site	Feet of land required for buffer zones[1]				
		50	100	300	500	1,000
			Acres			
0.1	31.7	5.6	11.7	40.6	76.9	199.7
.5	119.9	10.7	21.9	71.2	127.9	301.7
1.0	229.6	14.7	30.0	95.4	168.2	382.2
5.0	1,098.4	32.0	64.4	198.8	340.5	727.0
10.0	2,172.6	44.9	90.2	276.3	469.6	985.1
50.0	10,645.2	99.1	198.6	601.5	1,011.6	2,069.2
100.0	21,133.9	139.5	279.5	844.1	1,416.0	2,878.0

1 Assumes a square application site with the indicated equal width buffer zone surrounding the site.

Additional pretreatment of the wastewater prior to land application may also be used to reduce potential public health problems. Treatment processes such as activated sludge may be substituted for the aerated lagoon treatment system. Activated sludge treatment costs approximately 42.4 cents per 1,000 gallons for a 1-MGD facility (table 2). Aerated lagoon costs for this facility size are substantially lower, 13 cents per 1,000 gallons (see footnote 11). Substitution of activated sludge pretreatment for aerated lagoons adds 29 cents per 1,000 gallons to total treatment costs. The use of chlorination and buffer zones appears to be a more cost effective method for public health protection under the assumptions of this analysis than the use of additional pretreatment methods such as activated sludge.

Storage

In many U.S. regions, it may be impossible to apply wastes to land year round. Construction of wastewater storage facilities may be necessary. Based on climatic considerations, a recent EPA publication (18) recommends 80 days of storage for central Pennsylvania through central Illinois and up to 160 days of storage in northern Minnesota. Research at the Pennsylvania State University (5) indicates that storage may not be needed for irrigation of reed canarygrass or forestland. Since wastewater is generated continuously, wastewater that cannot be applied directly must be stored for later application. The cost of wastewater storage includes more than the costs of the storage lagoon. Since stored wastewater must be applied to the land at a future date, additional land for the application site and additional irrigation equipment are required. 18/ Average total costs are estimated to increase approximately 1.2 to 2 cents per 1,000 gallons for every week of storage capacity provided in the land application system. Due to economies of size, storage is more costly on a per unit basis for smaller communities. In addition to the cost of storing wastewater for later land application, a treatment authority may wish to have supplemental storage capacity available to meet emergencies caused by adverse weather or system malfunction. A week of additional lagoon storage capacity is estimated to cost from 1.5 cents per 1,000 gallons for a 0.1-MGD facility to 1.1 cents per 1,000 gallons for a 100-MGD facility.

A wastewater treatment authority may have an option available other than storage for those periods when the land application site cannot accept the wastes. The treatment authority may be able to discharge the wastewater directly to a stream. 19/ The wastewater in these cases has received secondary treatment (aerated lagoon) and, in many cases, may not significantly alter the

---

18/ It should be noted that storage and land requirements are not exogenously determined. Selection of a crop for irrigation implicitly limits the length of the irrigation season and the application rate which in turn determine the amount of land needed for wastewater irrigation. These relationships are addressed in the following two sections.

19/ Under the present laws regarding wastewater treatment, this option is not available. This discussion is presented to highlight the impact of such a change in the legal structure.

water quality of the stream. A stream may be able to accept wastes of a poorer quality during winter months since assimulative capacity is greater during colder periods of the year and stream flows are usually higher. The treatment authority will save the costs of wastewater storage for every week (1.2 to 2 cents per 1,000 gallons) that the wastes are discharged to a stream, as opposed to being stored for later land application.

Application Rate

Variations in the rate at which wastewater is applied to land significantly affect the character and performance of a land application system. At lower application rates, more land and thus more irrigation equipment are required to apply an equivalent volume of wastewater. At lower application rates, the expected level of nutrient removal or degree of wastewater treatment is higher. Bradley (1) found that decreases in the application rate significantly reduce nitrate leaching below the root zone (4-foot soil depth) for crop irrigation with wastewater.

The relationship between the application rate and changes in average total costs is shown in table 7. For example, increasing the application rate from 0.5 inch per week to 1 inch per week causes a decrease in average total treatment costs of about 27 cents per 1,000 gallons for solid-set systems and a decrease of 10 to 13.6 cents per 1,000 for center-pivot irrigation systems. Most of the advantages of increasing the application rate are reached at an application rate of 1.5 inches per week. Increases in the application rate beyond 1.5 inches per week do not result in large decreases in average total treatment costs since, as the application rate increases, the lower capital and operating requirements incurred to irrigate a smaller land acreage are partially offset by decreases in net crop revenue. Since it is assumed that crop yields and per acre costs of the farm operation are constant, irrigating more acres with a given quantity of water results in a significantly higher net crop revenue per 1,000 gallons. For example, net crop revenue from irrigating at a 0.5-inch per week application rate is estimated as 37.4 cents per 1,000 gallons as opposed to 9.4 cents per 1,000 gallons at a 2-inch per week application rate. Thus, if a community decides to reduce the designed application rate for its system to obtain better treatment of effluent, the cost impact will be smaller than anticipated. 20/

The relationship between average net crop revenue and average capital and operating costs brings to light a point alluded to earlier. With a capital subsidy, a community may find that local wastewater treatment costs are minimized by operating at a lower application rate. For example, average total costs for a 0.5-MGD solid-set land application system are 91.3 cents per 1,000

20/ The cost impact of reducing the application rate may be underestimated if crop yield, and thus net crop revenue per acre, is positively related to the application rate. In other words, net crop revenue per acre may be overestimated at the lower application rates. Bradley (1) found a statistically significant relationship between the application rate and crop yield for reed canarygrass and alfalfa.

Table 7--Decrease in average total cost estimates for 0.5-inch increases in the weekly application rate

Weekly application rate increase	Facility size (MGD)						
	0.1	0.5	1.0	5.0	10.0	50.0	100.0
	Decrease in cents per 1,000 gallons						
Solid-set:							
0.5-1.0	27.4	26.9	27.4	26.9	26.9	27.0	27.1
1.0-1.5	9.5	8.8	9.1	9.0	9.0	9.0	9.0
1.5-2.0	5.2	4.6	4.4	4.5	4.5	4.5	4.5
2.0-2.5	3.5	2.8	2.6	2.7	2.7	2.7	2.7
2.5-3.0	2.5	1.7	1.8	1.8	1.8	1.8	1.8
3.0-3.5	1.9	1.3	1.3	1.3	1.3	1.3	1.3
3.5-4.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0
Center pivot:							
0.5-1.0	13.6	12.8	12.7	11.2	10.7	10.1	10.0
1.0-1.5	5.0	4.5	4.3	3.9	3.7	3.4	3.4
1.5-2.0	2.9	2.2	2.1	2.0	1.9	1.7	1.7
2.0-2.5	2.1	1.2	1.3	1.2	1.2	1.0	1.0
2.5-3.0	1.6	.7	.9	.8	.8	.7	.7
2.0-3.5	1.2	.6	.7	.6	.6	.5	.5
3.5-4.0	1.0	.5	.4	.4	.4	.4	.4

Source: Cost estimates based on simulation model.

gallons (table 1) with a 2-inch per week application rate. If the community receives a 75-percent Federal construction subsidy under P.L. 92-500, the costs to the local community fall to 35.1 cents per 1,000 gallons. 21/ If the community selects a 1-inch per week application rate, average total costs are 104.6 cents per 1,000 gallons (an increase of 13.4 cents per 1,000 gallons). With a 75-percent capital subsidy, the costs to the local community fall to 34.5 cents per 1,000 gallons. At the lower application rate, the number of acres irrigated is doubled, since there is a fixed quantity of wastewater at an application rate which is 50 percent lower. This causes average local capital costs to increase by 5.2 cents per 1,000 gallons and average operating costs to increase by 3.5 cents per 1,000 gallons. The higher local costs for irrigation are offset by an increase in net crop revenue of 9.3 cents per 1,000 gallons due to the constant net revenue per acre being applied to the additional irrigated acreage. Therefore, average total local costs fall by 0.6 cent per 1,000 gallons. The community finds that it is better off or at least indifferent to the lower application rate in terms of average local costs with the 75-percent capital subsidy. With an 85-percent capital subsidy, average local costs are 2.4 cents per 1,000 gallons less at the lower application rate (1 inch per week).

A community anticipating rapid population growth may find this relationship working to its advantage. A lower application rate can be chosen for insignificant increases or possibly decreases in average total costs to the local community. As the community grows, additional treatment capacity need not be constructed. The application rate can be increased, which results in increased operation and maintenance costs but no additional construction costs.

Crop Selection

Selection of the crop or set of crops for wastewater irrigation influences the costs for land application systems. Net crop revenue from irrigation, the difference between gross crop revenue and crop management costs, varies among crops. The length of the irrigation season will vary depending upon the crop to be irrigated. The rate at which wastewater can be applied is also limited by crop selection. Certain crops may not be capable of removing the desired amount of nutrients from the site and thus their inclusion in the land application system may require a lower application rate or shorter irrigation season. Each of these factors affects the costs of wastewater treatment.

Net crop revenue estimates from land application of wastewater have been generated using two cropping models. The two models differ in their assumptions and generate substantially different estimates of net crop revenue. The Pound, Crites, and Griffes cropping model (10) assumes that crop yields, management costs, and revenues for a land application system will be similar

---

21/ Costs to the local community are defined as operating costs plus unsubsidized capital costs less net crop revenue. Unsubsidized capital costs include capital cost items that are not eligible for subsidies such as land for aerated lagoons and the community's share of cost items that are eligible for subsidy.

to those found in California using the best agricultural management practices. The second model, referred to as the Bradley cropping model, assumes yields from wastewater irrigation similar to those reported by Kardos (5). Crop management and revenues are assumed to apply to a location in central Pennsylvania (1).

Net crop revenue estimates for the two cropping models shown in table 8 show that crop selection and management influence the costs of land application systems. 22/ The Pound, Crites, and Griffes cropping model permits irrigation of alfalfa, reed canarygrass, corn silage, grain sorghum, barley, and cotton lint. The Bradley cropping model permits irrigation of alfalfa, reed canarygrass, corn silage, and corn grain. 23/ Alfalfa, corn silage, and grain sorghum provide the highest net crop revenues while reed canarygrass provides the lowest revenue in the Pound, Crites, and Griffes model (table 8). The Bradley model provides similar results although the absolute difference among net crop revenues for the various crops is lower. Bradley estimates a positive net crop revenue for reed canarygrass while the other model estimates a negative net revenue. 24/

The assumptions used to generate the net crop revenues estimates in table 8 may not hold in all cases. For instance, Bradley (1) indicates that in order to meet nutrient removal constraints, the irrigation season for corn may be 30 weeks per year, while reed canarygrass may be irrigated year round. Thus, a simple comparison of net crop revenues may be insufficient to decide between irrigation of particular crops. By accounting for possible changes in the irrigation season which accompany particular crops, average total cost estimates using the Bradley cropping model are related to a particular crop (table 9). The highest average net crop revenue for the crop irrigation alternatives listed in table 8 is for corn, but when changes in the irrigation season are taken into account, the average total costs for other cropping activities are lower. The least cost alternative is to irrigate reed canarygrass for 48 or 52 weeks per year. 25/ Irrigation of a mixed hardwood forest is less costly since there is less wastewater storage and thus fewer acres are irrigated.

22/ The analysis assumed that each crop is capable of providing some minimum level of nutrient removal, such as the U.S. Public Health Service standard for drinking water of 10 ppm of nitrate nitrogen.

23/ Additionally, the Bradley model permits irrigation of a mixed oak hardwood forest. Estimates for mixed hardwood forest irrigation are not presented in table 8 since forest irrigation requires modification of the irrigation network.

24/ A negative net crop revenue implies that revenues from crop sales do not offset the costs of cultivating and harvesting the crop.

25/ Bradley (1) estimates that reed canarygrass silage can be marketed at $15 per ton.

Table 8--Average net crop revenue estimates for two cropping models

Model and crop	Net revenue
	Cents per 1,000 gallons
Pound, Crites, and Griffes cropping model:	
Alfalfa	9.4
Reed canarygrass	-4.5
Corn silage	9.6
Grain sorghum	9.4
Barley	6.0
Cotton lint	2.6
Bradley cropping model:	
Alfalfa	4.6
Reed canarygrass	3.9
Corn silage	4.9
Corn grain	6.3

Irrigation of a forest is more expensive than crop irrigation since the distribution system must be altered and pumping pressures reduced in order to obtain an equal distribution of the effluent over the forest floor. Even with the higher costs of irrigating forests and the virtual absence of a salable crop, forest irrigation can be a least cost method for land application due to the longer irrigation season. If forestland is available at a lower cost, the relative cost effectiveness of forest irrigation will be improved. 26/

Crop selection also influences the rate at which wastewater may be applied to the land. Research has shown that reed canarygrass can receive a much higher application rate than mixed oak forests or corn, while still maintaining a fixed level of nutrient removal from wastewater (5). In fact, irrigation of mixed oak forests may require substantial reductions in the application rate to maintain an adequate level of treatment. The effects of altering the application rate discussed in the previous section can be incorporated into the cost estimates for particular crops to adjust properly for this effect.

26/ Irrigation of fast-growing forest products is not considered in this analysis. Their development and use for wastewater irrigation will improve the relative cost effectiveness of forest irrigation.

Table 9--Average costs for a 1-MGD solid-set irrigation system when the irrigation season is limited to account for a crop's ability to remove pollutants from the wastewater

Bradley cropping assumptions	Average capital costs	Average operating costs	Average net crop revenue	Average total costs
	Cents per 1,000 gallons			
Reed canarygrass irrigated for 40 weeks per year	61.0	17.9	3.9	75.0
Reed canarygrass irrigated for 48 weeks per year	48.3	17.1	3.3	62.1
Reed canarygrass irrigated year round	41.9	16.6	3.0	55.5
Corn silage irrigated for 30 weeks per year	78.7	19.3	6.6	91.4
Mixed oak hardwood forest irrigated for 40 weeks per year	65.3	19.9	.4	84.8
Mixed oak hardwood forest irrigated for 48 weeks per year	52.0	18.8	.4	70.4
Mixed oak hardwood forest irrigated year round	45.3	18.3	.3	63.3

CONCLUSIONS

Several implications for land application of wastewater have been identified from this analysis: the relative cost effectiveness of land application as an advanced wastewater treatment technique, changes in cost effectiveness as facility size changes, land costs, effluent transmission distances, public health constraints, storage requirements, changes in the application rate, and the importance of crop revenue. The relative impacts of the cost parameters are summarized in table 10.

Table 10--Comparison of the cost and revenue parameters analyzed for two alternative facility sizes

Item	Facility size (MGD) 1	10
	Cents per 1,000 gallons	
Costs:		
Solid-set irrigation	69.5	43.8
Center pivot irrigation	63.1	36.4
AWT1	77.5	30.0
AWT2	129.4	51.6
AWT3	144.5	62.1
Additional costs:		
Increase in land costs of $1,000 per acre	4.2	3.9
1 mile increase in pumping distance	3.3	0.9
Chlorination	2.4	1.0
Buffer zone: 100 feet	.7	.2
Buffer zone: 500 feet	4.1	1.2
One week of additional storage	1.4	1.3
Decrease in application rate from 2 to 1.5 inches per week	4.4	4.5
Net crop revenues: Pound, Crites, and Griffes' corn silage	9.4	9.4
Net crop revenues: Pound, Crites, and Griffes' reed canarygrass	-4.5	-4.5
Net crop revenues: Bradley's corn silage	4.9	4.9
Net crop revenues: Bradley's reed canarygrass	3.9	3.9

Land application is the least costly of the advanced wastewater treatment options examined. It also provides the highest level of pollutant removal (table 3). Of the two land application techniques studied, center-pivot irrigation costs were 2.5 to 8 cents per 1,000 gallons less than the costs for solid-set irrigation. As facility size increases, the relative cost advantage of land application decreases. An increase in facility size from 1 to 10 MGD results in about a 40-percent decrease in average costs for land application while, for the AWT options, average costs fall by approximately 60 percent (table 10). Therefore, it can be expected that land application would be seriously considered more often by smaller communities than by larger ones.

The use of aerated lagoons as a pretreatment technique in land application systems improves the cost effectiveness of land application. Aerated lagoons, while not a cost effective pretreatment method for most advanced wastewater treatment techniques, provide sufficient pretreatment for land application. If other pretreatment techniques are considered, land application is still less costly for smaller communities (less than 5 MGD).

When compared to the impacts of the other cost parameters in table 10, land costs do not exert an overwhelming impact on total treatment costs. Assuming that land values do not appreciate or depreciate over the life of the facility, a $1,000 per acre increase in land costs cause a 6-percent increase in average total costs for a 10-MGD facility. If land values are assumed to depreciate as a result of the land treatment activity, the impact of land costs will be slightly higher while, if land is assumed to appreciate in value, land costs may fall to zero.

A community may have to pump its wastewater away from the community in order to find a suitable site for land application. A 1-MGD facility will incur costs of 3.3 cents per 1,000 gallons for each mile that wastewater is pumped and a 10-MGD facility will incur costs of 0.9 cent per 1,000 gallons per mile. Pumping costs can be traded off against land costs. A 1-MGD facility can pump its effluent 1 additional mile to obtain a $1,000 per acre decrease in land costs while the 10-MGD facility can go over 4 miles. Smaller land treatment systems will tend to be located nearer the community due to their pumping costs. Smaller communities will be willing to pay slightly higher prices for land to avoid pumping although they may not need to since development pressures on land prices are likely to be lower in these communities.

Examination of the health constraints relating to land application reveals that buffer zones and chlorination may be highly cost effective methods for minimizing health problems. A 500-foot buffer zone surrounding a 1-MGD facility will add approximately 4 cents per 1,000 gallons to total treatment costs and 1.2 cents per 1,000 gallons to total treatment costs for a 10-MGD facility. If it is assumed that this buffer zone can be farmed, the costs will be reduced substantially. Buffer zones may also provide an area for future expansion if chlorination can be substituted in the future. Chlorination costs 2.4 cents per 1,000 gallons for a 1-MGD facility and 1 cent per 1,000 gallons for a 10-MGD facility. In many cases, chlorination will be a cost effective method for reducing health problems. Chlorination will be a more cost effective alternative if land costs are greater than or equal to those assumed in this analysis and it is assumed that there is no positive net crop revenue from the unirrigated buffers. Other methods for reducing health problems are not likely to be as cost effective as chlorination and buffer zones.

A week of storage adds 1.2 to 2 cents per 1,000 gallons to the cost of a land application system. This cost estimate includes lagoon costs plus the costs of the extra land and irrigation equipment required to apply the stored effluent to the land at a later date. If a community is required to store its wastewater for 10 weeks per year, as has been recommended for central Pennsylvania based on climatic constraints, storage costs will be 14 cents per 1,000 gallons for a 1-MGD facility. Effluent storage added to deal with adverse weather and system malfunctions can add to costs.

The rate at which the wastewater is applied to the land is an important influence on land application costs. As the application rate is increased from low rates to higher rates, average total costs decrease. The largest cost decreases occur as the application rate is increased to 1.5 inches per week. As the application rate increases, average capital and operating costs decrease. These cost decreases are partially offset by reductions in net crop revenue, since fewer acres are irrigated for a given size of facility. With a capital subsidy, a community may find that its costs are reduced by selecting a lower design application rate. The increased crop revenue may offset the increased operating and unsubsidized capital costs. The additional irrigated acreage associated with lower application rates provides some excess capacity for future growth since the application rate can be increased and the same acreage irrigated. Thus, a greater quantity of wastewater can be treated per year with minimal increases in annual operating costs.

Crop selection can significantly alter the costs of land application. Estimates of net crop revenue range from -4.5 cents per 1,000 gallons for reed canarygrass to 9.4 cents per 1,000 gallons for corn silage. The cost estimates vary depending upon the crop irrigated and the assumptions used to generate the cost estimates. Some crops may be irrigated for longer periods of time than others. Application rates will vary among crops in order to maintain adequate levels of nutrient removal. Thus, a strict comparison of crop revenues is not applicable since as the irrigation season and application rate change, the capital and operating requirements of the system also change. If crops such as reed canarygrass cr forest can be irrigated for 48 to 52 weeks per year, average total costs will be lower than the costs for irrigating corn silage or alfalfa for a shorter time per year (30 or 40 weeks). Research by Kardos (5) indicates that crops such as reed canarygrass may be capable of being irrigated at higher application rates depending upon local soil characteristics. This will further reduce the costs of wastewater irrigation.

LITERATURE CITED

(1) Bradley, Edward B. "Optimal Utilization of Land in Municipal Wastewater Land Treatment Systems: An Economic Analysis." Ph.D. dissertation (1978), The Pennsylvania State University.

(2) Craig, Robert G., and Harry P. Mapp, Jr. 1976. "The Importance of Locational Characteristics in Determining Rural Land Prices." Journal of the Northeastern Agricultural Economics Council, Vol. V, No. 2.

(3) Environmental Protection Agency. 1975. Evaluation of Land Application Systems. Technical Bulletin, EPA-430/9-75-001.

(4) Environmental Protection Agency. 1976. An Analysis of Construction Costs Experience for Wastewater Treatment Plants. Technical Bulletin, EPA-430/9-76-002.

(5) Kardos, Louis T., William E. Sopper, Earl A. Meyers, Richard R. Parizek, and John B. Nesbitt. 1974. Renovation of Secondary Effluent for Reuse as a Water Resource. U.S. Environmental Protection Agency, Environmental Protection Technology Series, EPA-660/2-74-016.

(6) McDonnell, Archie (ed.). 1974. Workshop on Research Needs Related to Recycling Urban Wastewater on Land. Institute for Research on Land and Water Resources, University Park, Pennsylvania.

(7) National Association of State Universities and Land Grant Colleges. 1973. Recycling Municipal Sludges and Effluents on Land. Washington, D.C.

(8) Pound, Charles E., and Ronald W. Crites. 1973. Wastewater Treatment and Reuse by Land Application. Vol. 1. U.S. Environmental Protection Agency, Environmental Protection Technology Series, EPA-660/2-73-006a.

(9) ______________. 1973. Wastewater Treatment and Reuse by Land Application. Vol. 2. U.S. Environmental Protection Agency, Environmental Protection Technology Series, EPA-660/2-73-006b.

(10) ______________. 1975. Costs of Wastewater Treatment by Land Application. Prepared for Environmental Protection Agency, Technical Report EPA-430/9-97-003.

(11) ______________. 1975. Cost-Effective Comparison of Land Application and Advanced Wastewater Treatment. Prepared for Environmental Protection Agency, Technical Report, EPA-430/9-75-016.

(12) Snell, Abner W. (ed.). 1974. Proceedings of Workshop on Recycling Municipal Wastewater on Land. Water Resources Research Institute. Clemson, South Carolina.

(13) Sopper, William E. 1974. Research Needs Related to Recycling Urban Wastewater on Land. Institute for Research on Land and Water Resources, University Park, Pennsylvania.

(14) Sorber, Charles A., Howard T. Bausum, Stephen A. Schaub, and Mitchell J. Small. 1976. "A Study of Bacterial Aerosols at a Wastewater Irrigation Site." Journal Water Pollution Control Federation, Vol. 48, No. 10.

(15) Sullivan, Richard H., Morris M. Cohn and Samuel S. Baxter. 1973. Survey of Facilities Using Land Application of Wastewaters, APWA research foundation report for Environmental Protection Agency.

(16) Van Note, Robert H., Paul V. Herbert, Ramesh M. Patel, Craig Chupek, and Lester Feldman. 1975. A Guide to the Selection of Cost-Effective Wastewater Treatment Systems. Prepared for Environmental Protection Agency, Technical Report, EPA-430/9-75-002.

(17) Walker, John M., 1976. Wastewater: Is Muskegon County's Solution Your Solution? Region V, Environmental Protection Agency, Chicago, Illinois.

(18) Whiting, R. M., 1976. Use of Climatic Data in Estimating Storage Days for Soils Treatment Systems. Prepared for Robert S. Kerr Environmental Research Laboratory, Environmental Protection Agency, Ada, Oklahoma. Environmental Protection Technology Series, EPA-600/2-76-250.

(19) Young, C. Edwin. 1976. The Cost of Land Application of Wastewater: A Simulation Analysis. Economic Research Service, U.S. Department of Agriculture, Technical Bulletin 1555.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1978 261-496/135

END