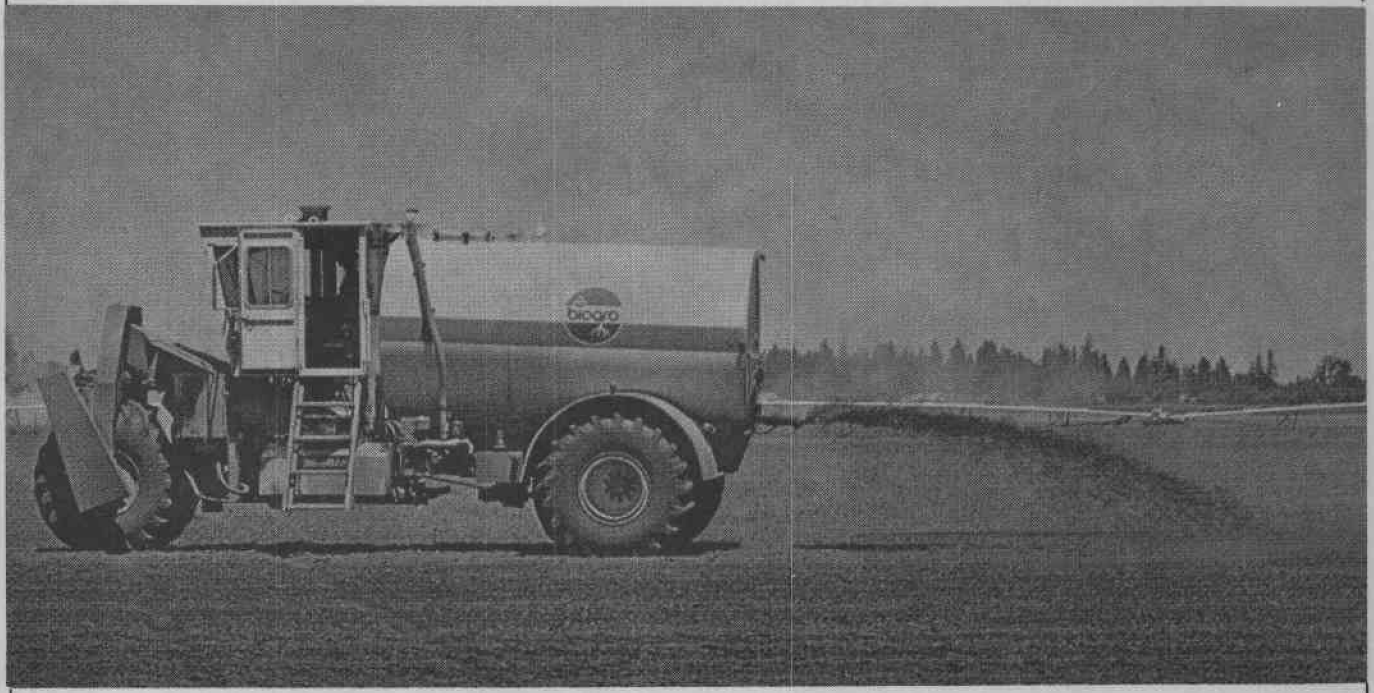


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# Land Application of Treated Sludge Sewage: Guidelines for Communities and Farm Operators



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## LITERATURE CITED

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Land Application of Treated Sewage Sludge:  
Guidelines for Communities and Farm Operators

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LAND APPLICATION OF TREATED SEWAGE SLUDGE:  
GUIDELINES FOR COMMUNITIES AND FARM OPERATORS

Strict environmental standards for discharge of municipal sewage effluents and sludges have made many existing treatment facilities inadequate. Even cities whose treatment plants presently meet environmental standards are being pressured by higher costs and population growth to review present operations.

Research and current municipal practice suggest that land application of sludges and effluents is an economically attractive proposition for many smaller cities and may be feasible for some larger population centers. Furthermore, the 1972 amendments to the Federal Water Pollution Control Act (PL 92-500) and Federal Cost Effectiveness Analysis Guidelines (40 CFR 35) require applicants for waste treatment systems grants to consider land application alternatives.

At the same time, farmers may find sludge to be a low-cost soil conditioner and source of crop nutrients. The federal grant requirements and changing economic conditions have increased the potential for mutually beneficial agreements between sewerage agencies and farmers regarding the application of treated sewage sludge to privately owned farmland.

This report is intended as a guide for community leaders concerned with planning for sewage sludge disposal and for farmers considering application of treated sewage sludge to their land. Because the perspectives of both the sewerage agency and the farmer are explicitly recognized, this guide may serve as a starting point for discussions between the public agency and the potential cooperators in a land-application program. Decisions about sludge disposal are primarily technical decisions that must be made by those responsible for sewage treatment in a municipality, on the basis of engineering and economic feasibility studies. At the same time, the public has a legitimate and often compelling interest in such decisions, particularly in situations involving land application. A decision unacceptable to the public, no matter how well founded technically and economically, will be extremely difficult to implement. This publication may be useful as part of an education program for the people on whom the success of a land application ultimately depends--the citizens of affected municipalities.

Land application of treated sludge has a long history in this country and is a common method of sludge "disposal" among the smaller cities in Oregon and elsewhere. One study shows that more than half the cities using land disposal had populations below 5,000 in 1968 (11).<sup>1/</sup> Larger cities have turned to other methods because larger volumes of sludge require larger amounts of land for disposal--and large amounts of farm land are not readily available in the larger metropolitan areas.

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<sup>1/</sup> Numbers in parenthesis refer to published studies listed under Literature Cited at far end of this report. The authors recommend these as references for those interested in further study.

## What is Sludge?

The secondary biological treatment of municipal sewage yields two end products:

- (1) effluent--a relatively clear liquid containing less than 0.01 percent solids, and
- (2) sludge--a semiliquid, brownish or black, musty-smelling fluid containing 0.5 to 10 percent solids, depending on type and level of treatment (5).

Every 1,000 gallons of domestic wastewater will ordinarily yield around 998 gallons of treated effluent and 2 gallons of treated (digested) sludge. (Fair, Geyer, and Okun, 1968, cited in Salotto, et. al., MSU Conference 1974.) The liquid effluent is ordinarily released directly into a river: The sludge must be disposed of in some other way than by direct release into a watercourse.

A municipality with 10,000 people may generate one million gallons per day of domestic wastewater.<sup>2/</sup> The sewage plant that treats this wastewater would have an average of 2,400 gallons (5 percent solids) of treated sludge per day for disposal or reuse. These 2,400 gallons would contain about one-half ton of digested solids. If this sludge were applied to land at a rate of four tons of solids<sup>3/</sup> per acre per year, the city would need about 45 acres of land for sludge disposal.

Sludge does contain some plant nutrients. On a dry matter basis, digested sludge contains 3.5 to 6.5 percent nitrogen, 1.8 to 8.7 percent phosphoric acid and up to 0.84 percent potassium. This is equivalent to 4-7-1 fertilizer. Sludge also contains heavy metals, often in rather high concentrations which may render the sludge unacceptable for land application. Most Oregon communities presently apply treated sludge to nearby land, often to municipally owned land such as airports.

### Is Land Application of Sludge Viable in Your Community?

The feasibility of land application vis-a-vis other sludge disposal systems depends on a number of factors. Interdisciplinary studies are needed to determine whether land application is an economically attractive and technically feasible method of sludge disposal for a particular community.

These are the considerations that determine whether land application is a viable alternative:

Characteristics of the sludge, particularly chemical and biological composition. The plant-nutrient content determines the fertilizer value of the sludge. High concentrations of heavy metals such as zinc and copper in the sludge

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<sup>2/</sup> Commercial and industrial wastewater produced in a community would increase this figure by an amount that would depend on the amount and type of commercial and industrial activity.

<sup>3/</sup> The figures listed are for illustration only and do not imply an acceptable application rate.

may render it unacceptable for land application.

Volume and flow variability of the sludge. The economic feasibility of different sludge disposal systems varies as the volume of sludge increases.

Existing capital investments. Communities with excess sludge storage capacity in their existing plant may be able to consider an economical land application system not feasible for a similar community without such excess capacity.

Characteristics of land available for land application. Economic access to suitable land in sufficient quantity is a prerequisite to land application. The availability of large tracts of suitable municipally owned land (such as airports and golf courses) may make land application a more attractive option. A community's soil types, land ownership patterns, zoning, land use patterns will affect the potential for land application of sludge.

Climate (precipitation and temperature, particularly). Climate may limit the kinds of feasible disposal system, and the types of cropping patterns possible.

Capital availability (bonding limits and availability of grants) and capital cost. The best may be too expensive for the community to obtain.

The public attitude toward treated sludge. This consideration can be critical: opposition to the use of sludge in a community, whether founded or unfounded, can stop a program for agricultural use. Proper management is necessary to ensure that pathogens and odor (two principal concerns of the public) are controlled. Farmer attitudes toward sludge use are also important in situations that require the application of sludge on privately owned land.

These considerations will be discussed in greater detail in the context of the points in the decision process in which they are most important.

There are four interdependent sets of decisions involved in land application of sludge:

1. Selection of Application Sites. Where and how good are the potential application sites (and are they publicly or privately controlled)?
2. Sludge Handling Alternatives. How is sludge to be handled (i.e., stored and transported to the application site)?
3. Considerations for Sludge Application to Cropland. How is the sludge to be applied (i.e., what application rates and cropping patterns)?
4. What Price for Sludge. If sludge is to be delivered to farmers on private land, what price, if any, should be charged for the sludge?

The identification and selection of potential application sites must be done before the other decisions can be made. Once the potential application sites are selected, it can be determined how far the sludge must be transported, how the sludge can be applied and whether application will be publicly or privately managed, and price to be charged.

These four decisions are discussed in order.

### Selection of Application Sites

The availability of suitable potential application sites is critical to the feasibility of land application. Many municipalities apply sewage sludge to municipally-owned land (such as golf courses and airports). Others deliver or sell the sludge to private landowners. A 1973 survey in the southern United States (11) gives some indication of the extent to which these various alternatives are being used (See Table 1). Based on responses from 50 municipalities, there is about an even split between municipal ownership and either delivering or selling the sludge to private land owners. Each alternative has different implications for capital requirements, operating costs, and management of the system.

There are advantages and disadvantages to each alternative. The obvious disadvantage with municipal ownership is the large capital cost involved if the municipality must own land exclusively for the purpose of sludge application. The major advantage of a system for direct delivery to individual farmers is the avoidance of large capital outlays for land. This is particularly true where there is strong sentiment against public ownership of land. However, there are disadvantages to private application sites as well. Operating costs will be higher for delivering sludge to private land owners. Transportation distances may be longer and it may necessitate moving the unloading and application equipment from site to site. A higher level of management is needed with private land ownership in order to maintain proper control over what may be scattered application sites. The manpower costs for monitoring non-contiguous sites is greater. Also there is the risk of not having a disposal site if no one can be found to take the sludge during a particular time of the year. Some mix of publicly and privately owned land may provide both the low risk and low transportation and coordination costs associated to private landowners.

An important consideration in municipal ownership is the opportunity for multiple use. Multiple use, i.e., using land for some purpose in addition to sludge application, increases the attractiveness to the public of proposals for land acquisition and application.

### Sludge Handling Alternatives

Handling treated sewage sludge prior to land application involves storage of sludge and transporting sludge to the application site. The sizing of storage facilities and the possible modes of transportation (barge, tank truck, dump truck, pipeline) depend, among other considerations, on whether the sludge is dewatered (reduced from a liquid containing approximately 5 percent solids to cake containing 30 percent solids). Whether dewatering makes economic sense depends, in turn, on the volume of sludge and the distance to potential application sites.

Three alternative sludge handling methods are discussed here. These alternatives are represented schematically in Figure 1. They include:

Table 1. Land Control Alternatives for Sludge Disposal.

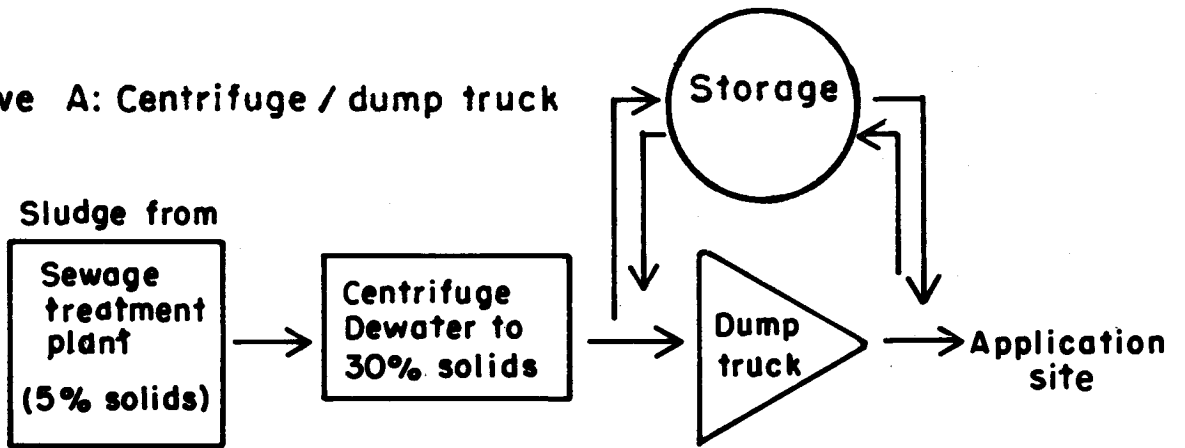
Alternative	Number of municipalities <sup>1/</sup>
Purchase land and operate . . . . .	18
Purchase land and contract operation . . . . .	8
Lease land and operate . . . . .	0
Lease land and contract operation . . . . .	0
Deliver to private landowners . . . . .	14
Sell to private landowners . . . . .	<u>10</u>
Total, all alternatives . . . . .	<u>50</u>

<sup>1/</sup>1973 data. Source is Young and Carlson (11).

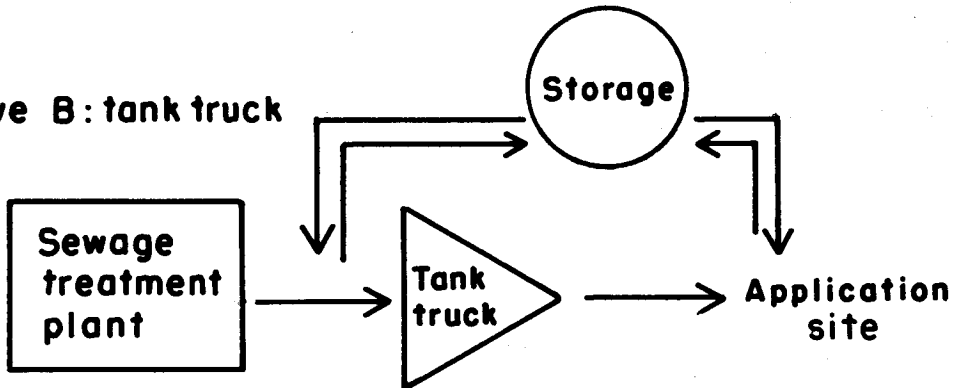


Figure 1. Alternative Sludge Handling Systems

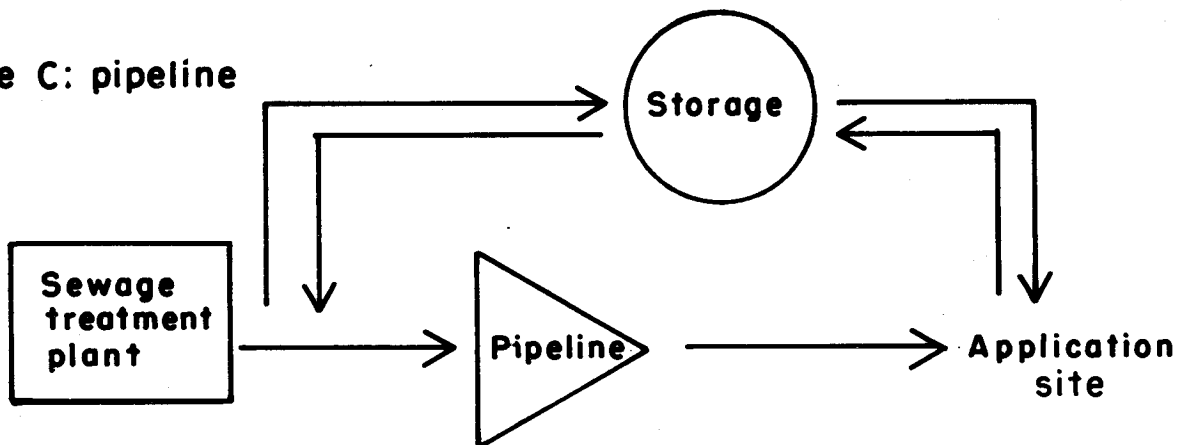
Alternative A: Centrifuge / dump truck



Alternative B: tank truck



Alternative C: pipeline



### A. Centrifuge/dump truck

In Alternative A, liquid sludge (about 5 percent solids) is dewatered with a centrifuge to a cake containing approximately 30 percent solids. This cake is stored in a concrete surface tank. It is transported in a dump truck to the application site. (Sludge can be stored either at the sewage plant or near the application site, either before or after it is transported. The discussion here assumes storage before transporting.)

### B. Tank truck

Under Alternative B, the sludge is not dewatered. This alternative requires a much larger tank for storage, and a tank truck for delivery.

### C. Pipeline

Under Alternative C, liquid sludge (5 percent solid content) is stored in a large concrete storage tank, either before or after transport in a pipeline.

Table 2 shows the estimates of capital investment required for the three alternatives for three different sizes of sewage treatment plants, assuming a distance of 20 miles between sewage plant and application site, an average of 215 days per year in which sludge can be applied, and an application rate of 40 dry tons/acre/year. The three alternative sizes were chosen to represent small, medium sized, and large plants in Oregon.

Annual fixed and operating costs were calculated for each of the three alternatives for three different sizes of sewage plant. Table 3 summarizes these estimates. The data and estimating procedure are taken from Kasper et. al. (2) and are based on 1973 prices for Southern New Jersey. While present costs would be higher, relative costs among the different alternatives would be expected to be about the same. Total fixed costs are those resulting from the initial investment and the administrative overhead necessary to run the plant. They include a cost for depreciation of capital (straight-line depreciation based on a 20-year life with zero salvage value) and an interest charge on invested capital of 7.5 percent. Also included are taxes, insurance, and salaries. These costs do not change as the volume of sludge rises within the capacity of the plant.

Variable costs are those that change as the volume of sludge changes. These include certain operating costs (the costs of power to run the centrifuge and pumps, the cost of fuel for vehicles, wages of those required to handle increased volumes) and maintenance costs (repairs and service costs for equipment and vehicles). The Appendix contains a breakdown of the costs included in these tables.

### Selection criterion

The sludge handling system is selected from among technically feasible alternatives. It should: meet environmental standards, be acceptable to the public, and be able to be financed by the municipality, not push the municipality beyond the limits of its capacity to bond. Within these constraints, the criterion for selection will ordinarily be an economic one: select the system that minimizes total cost per gallon of liquid sludge--that is, the least costly system. Which sludge handling method is the least costly generally depends on the volume of

Table 2. Capital Investment Required for Three Sludge Handling Alternatives.  
(1973 prices)<sup>1/</sup>

Alternative and equipment	Capital investment by size of sewage plant <sup>2/</sup>		
	.5 MGD plant	10 MGD plant	50 MGD plant
<b>A. Centrifuge/dumptruck</b>			
Centrifuge . . . . .	\$ 19,200	\$ 70,000	\$ 190,000
Dump trucks . . . . .	17,000	17,000	85,000
Concrete surface tanks . . . . .	4,540	91,100	455,000
Administration bldg. . . . .	20,000	25,000	30,000
<b>TOTAL</b>	<b>\$ 60,740</b>	<b>\$ 203,000</b>	<b>\$ 760,000</b>
<b>B. Tank truck</b>			
Tank trucks . . . . .	\$ 17,000	\$ 85,000	\$ 391,000
Concrete surface tanks . . . . .	27,300	547,000	2,730,000
Administration bldg. . . . .	20,000	25,000	30,000
<b>TOTAL</b>	<b>\$ 64,300</b>	<b>\$ 657,000</b>	<b>\$3,151,000</b>
<b>C. Pipeline</b>			
Pipeline . . . . .	\$2,723,000	\$2,723,000	\$3,038,000
Concrete surface tanks . . . . .	27,300	547,000	2,730,000
Administration bldg. . . . .	20,000	25,000	30,000
<b>TOTAL</b>	<b>\$2,770,300</b>	<b>\$3,295,000</b>	<b>\$5,798,000</b>

<sup>1/</sup>Source: Adapted from estimates made for Southern New Jersey by Kasper et al. (2).

<sup>2/</sup>Plant capacity expressed in millions of gallons per day (MGD) of raw sewage.

Table 3. Annual Fixed and Variable Costs for Three Sludge Handling Alternatives.<sup>1/</sup>

Alternative and equipment	Size of sewage plant <sup>2/</sup>		
	0.5 MGD	10 MGD	50 MGD
<u>Alternative A</u>			
Annual fixed costs	\$ 50,551	\$ 60,370	\$175,400
Centrifuge	\$ 1,690	\$ 6,130	\$ 12,600
Dump truck	21,800 <sup>3/</sup>	21,800	109,000
Storage tank	261	5,240	26,200
Administration	26,800	27,200	27,600
Annual variable costs	9,290	57,570	287,800
Centrifuge	2,520 <sup>4/</sup>	50,800 <sup>4/</sup>	254,000
Dump truck	6,770 <sup>4/</sup>	6,770 <sup>4/</sup>	33,800
Total annual costs	\$ 59,841	\$117,940	\$463,200
<u>Alternative B</u>			
Annual fixed costs	\$ 50,170	\$167,700	\$685,600
Tank truck	\$ 21,800 <sup>3/</sup>	\$109,000	\$501,000
Storage tank	1,570	31,500	157,000
Administration	26,800	27,200	27,600
Annual variable costs	6,770	33,800	156,000
Tank truck	6,770 <sup>4/</sup>	33,800	156,000
Total annual costs	\$ 56,940	\$201,500	\$841,600
<u>Alternative C</u>			
Annual fixed costs	\$251,370	\$555,070	\$425,600
Pipeline	\$223,000	\$223,000	\$241,000
Storage tank	1,570	31,500	157,000
Administration	26,800	27,200	27,600
Annual variable costs	22,000	36,600	102,700
Pipeline	22,000	36,600	102,700
Total annual costs	\$273,370	\$591,670	\$528,300

<sup>1/</sup>Source: Adapted from estimates used in study by Kasper et. al. (2).

<sup>2/</sup>Plant capacity expressed in millions of gallons per day (MGD).

<sup>3/</sup>These figures are taken from Table 13, p. 48 of Kasper et. al. (2). They include \$18,300 of "quasi-fixed costs": Salaries and wages (\$15,800), insurance (\$2,100), and vehicle registration (\$400). Since neither of these alternatives requires a full-time employee to transport the sludge from a .5 MGD plant, these estimates overstate the fixed costs.

<sup>4/</sup>These estimates are taken from Table 17, p. 57 of Kasper et. al. (2). They assume that the same number of sludge hauling trips would be required for (1) the .5 MGD plant under Alternative A, (2) the 10 MGD plant under Alternative A and (3) the .5 MGD plant under Alternative B. This assumption is not very realistic and overstates the variable costs for both of the .5 MGD plant alternatives.

sludge, the distance to the application site, and the cost of availability of capital.

### Volume of sludge

Figure 2 shows the relationship between cost of handling per 1,000 gallons of sludge, and the total volume of sewage (2). These estimates assume a distance of 20 miles from sewage plant to application site and that plants are operating at nearly their design capacity. As the volume of sludge increases, the type of system that is least costly changes. For small plants (.5 million gallons per day--MGD-- of sewage) the tank truck and centrifuge/dump truck alternative appear to cost nearly the same. Both are far below the cost of a pipeline system. For medium sized plants (10 MGD) and large plants (50 MGD) the centrifuge/dump truck alternative costs the least. While further research is needed to verify extrapolations, extensions of the curves beyond the 50 MGD point suggest that at about 60 MGD the pipeline alternative may begin to cost less than either of the other alternatives.

### Distance to application site

The second factor which affects the selection of the least-cost alternative is the distance from treatment plant to disposal site. We used Rutgers University data (2) to estimate cost curves relating cost/1,000 gallons of sludge and distance to the land application site. These estimates are presented in Figures 3, 4, and 5.

For small (.5 MGD) plants (Figure 3) the pipeline alternative, not shown, is prohibitively expensive at any distance under 40 miles, costing \$500 per 1,000 gallons of sludge. (For those who are accustomed to thinking in terms of dry tons or cost per dry ton, these figures can be converted by multiplying the dollars by about 4.4; this is more than \$2,000 per dry ton.) If a small plant can apply the sludge within a 5-mile radius, the tank truck alternative costs less per 1,000 gallons of sludge than the centrifuge/dump truck alternative. Beyond the 5 miles centrifuge/dump truck alternative costs slightly less for these small plants. This depends on the assumptions mentioned earlier about storage.

For medium (10 MGD) sized plants (Figure 4) the cost drops to less than \$20 per 1,000 gallons of 5 percent sludge for both alternatives employing trucks. For these plants the centrifuge/dump truck alternative is consistently, for any distance, lower than the tank truck alternative, although the difference is smaller the less the distance from the plant. (It was not possible to compute a curve for the pipeline alternative, but the cost appears to be quite a bit higher than for either of the other two--on the order of \$30 per 1,000 gallons.)

For the largest (50 MGD) plants (Figure 5), if the distance from the treatment plant to the land application site is small, the centrifuge/dump truck alternative is least costly. At about 10 miles, the pipeline becomes, and continues to be, the least costly alternative.

### Capital cost and availability

The capital investment required for each of these alternatives is significantly different (Table 2). The estimates assume a distance to land-application site of 20 miles.

Figure 2.

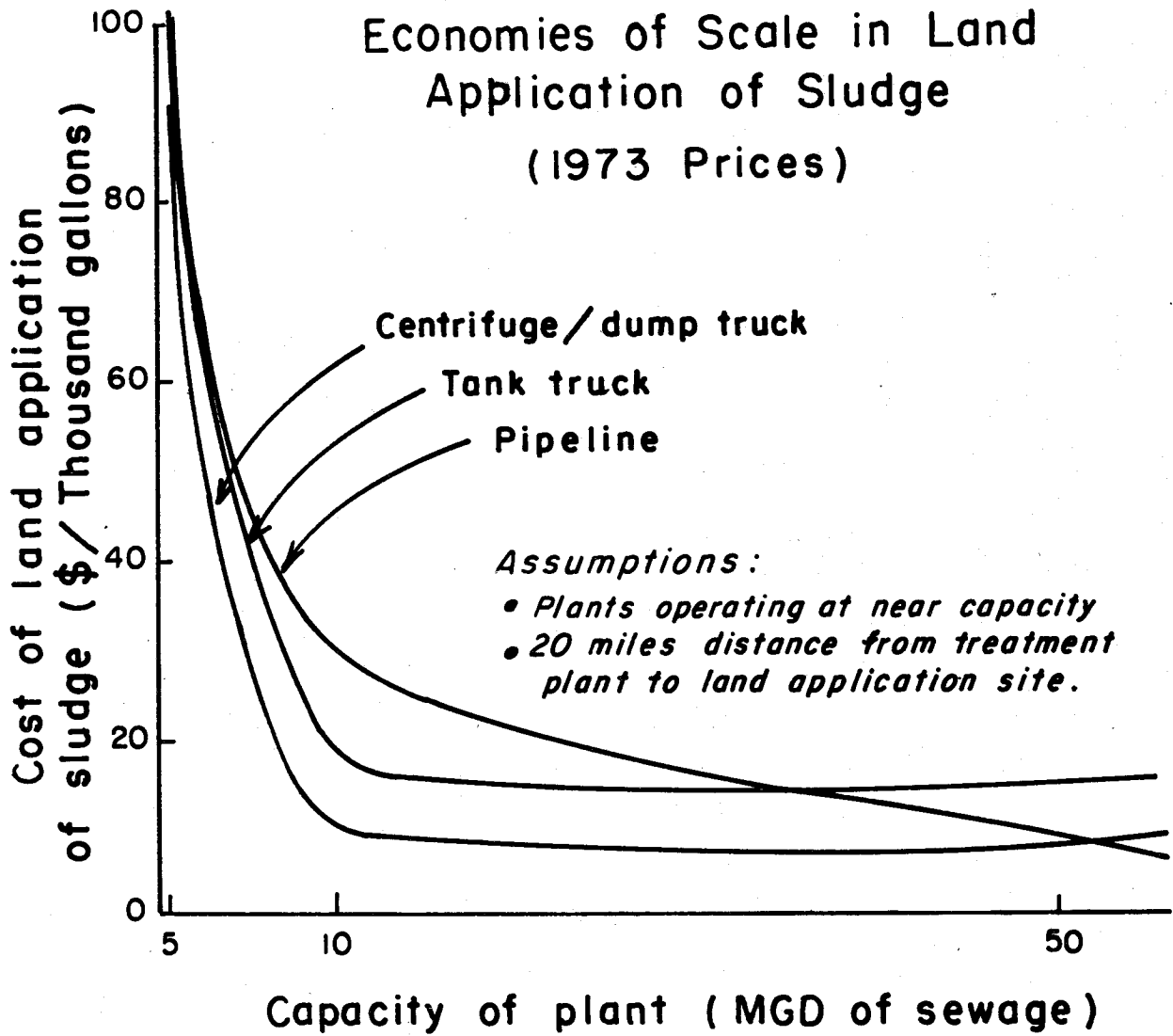


Figure 3.

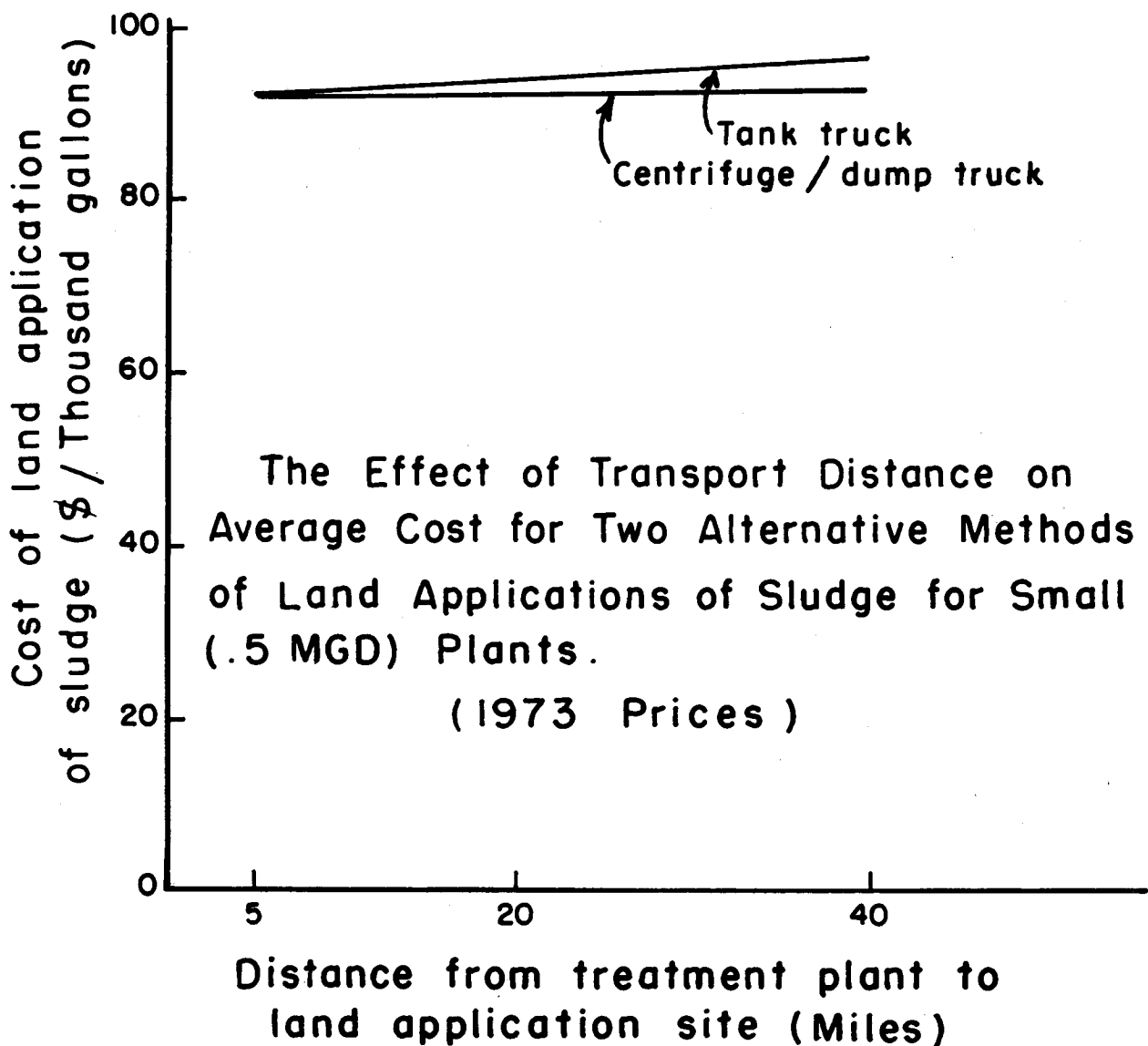


Figure 4.

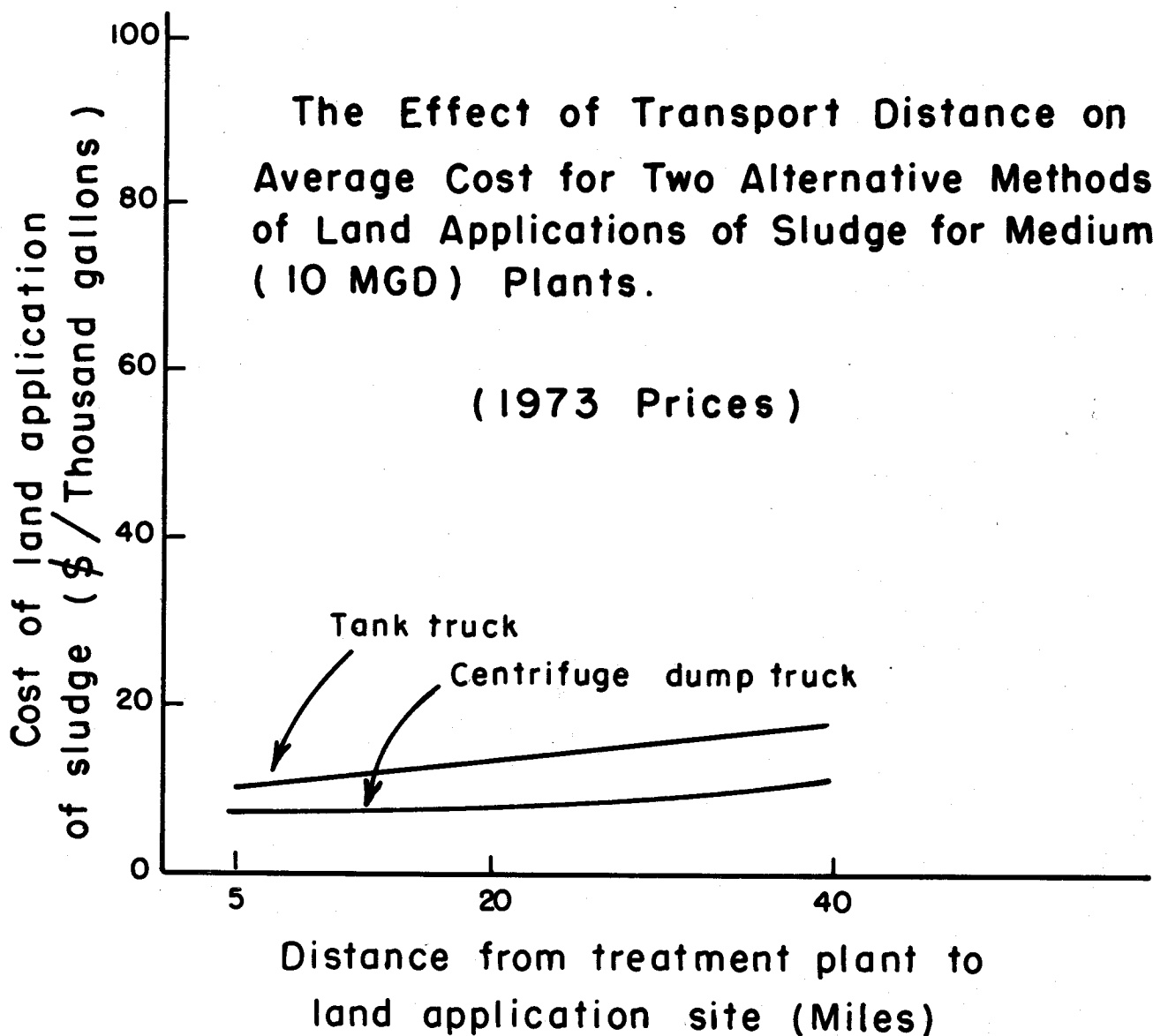
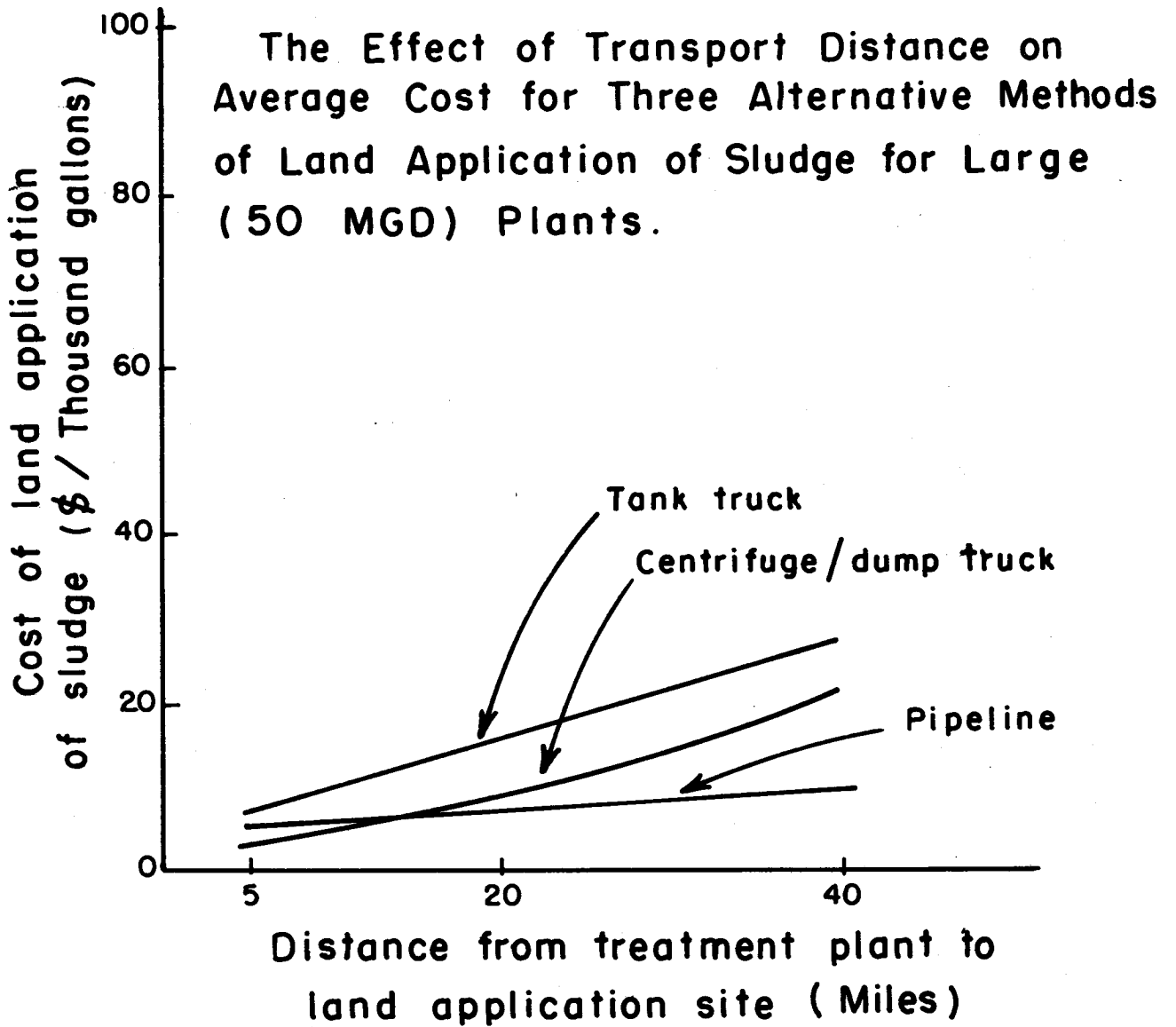




Figure 5.



The centrifuge/dump truck alternative requires the least capital investment for all plant sizes. The dewatered sludge requires one-sixth the storage facility the other alternatives require. It was clear from Table 3, however, that the centrifuge/dump truck alternative was not the least costly alternative for small sewerage operations, even though initial capital outlay was the lowest.

A municipality may not be able to select the least costly alternative if capital to finance this alternative is not available because (1) the bond required to finance the improvement might push the municipality beyond its legal or financial capacity to bonds, or (2) grants to offset part of the cost of the least costly system are unobtainable.

### Considerations for Sludge Application to Cropland

The application of sludge to cropland involves two decisions: what crops should be grown on land to which sludge is applied, and at what rate should the sludge be applied.

These decisions must be made whether the sludge is applied on municipal or private land. The different management objectives of sewerage agencies and farmers suggest that each might select different application rates. The principles governing these choices are the same, however.

### Selection of the cropping patterns

The production of crops "soaks up" the nitrogen and minerals to prevent pollution and reduce the cost of waste disposal. The crops speeds infiltration of water and liquid wastes, reduce soils and nutrient losses through erosion, reduce organic matter and plant nutrient content of runoff to surface streams, and reduce deep percolation of nutrients to groundwater. Table 4 summarizes the types of crops to which sewage effluent is applied in California (11). The most used were pasture and fodder crops. Several municipalities used sewage effluent to irrigate golf courses and landscape, which are used daily by the general public. The only precautions taken in the applications covered in the study were chlorination and spraying at times when facilities are not in use.

In Washington County, Oregon, sludge is being applied to wheat and, with limited applications, in clover. The farmer needs to consider several factors in selecting crops for the application of sewage sludge. The rate of nutrient removal is important. If the sludge is available to the farmer at no cost, farmers may seek to select crops that utilize relatively more of the elements in sludge.

Recent work done at Oregon State University shows the economic impact of sludge application to several different crops (7).

Sludge can be used on some crops more advantageously than others. Crops such as bush beans and spring barley are not economically viable alternatives. Tall fescue grass would be a feasible alternative for publicly owned land because of its

Table 4. Land Treatment Crops and Activities in California<sup>1/</sup>

Use	Number of sites	Proportion of total
		Percent
Pasture and fodder crops . . . . .	50	37
Agricultural crops . . . . .	40	30
Golf course and landscape . . . . .	30	22
Recreational lakes . . . . .	6	5
Combinations . . . . .	8	6
Total . . . . .	134	100

<sup>1/</sup>Source: David G. Deaner, 1971, as cited in Young and Carlson (11).

ability to utilize large amounts of nitrogen. The important point is look for crops that can utilize high levels of sludge application. Research at the University of Illinois (6) found that crops using large amounts of sludge nitrogen are the most desirable. The economic benefits from using heavier levels of sludge outweigh the differences in net revenue between crops. For this reason, double cropping systems were found to be superior to single cropping and both of these were superior to crop rotations where crops with low nitrogen requirements were included. Similar results were obtained in Oregon with single cropping.

It should be noted that sludge application to crop land entails changes in cultural practices, timing rates, and utilization of operator's labor. These changes will increase the operator's production costs. Consequently, evaluating sludge only by its nutrient composition will overstate its value to the farm operator.

Some of the examples of high-nitrogen-using crops are corn silage, removing 136 pounds of N per acre, coastal bermuda hay removing 243 pounds and reed canary-grass hay with 169 pounds of N removed. Other examples would be sudan grass hay and tall fescue hay. To the farm operator, crops such as winter wheat are more desirable in many areas of Oregon because of its revenue potential. Crops such as wheat or corn may require adjustments in the application rate and timing of application. However, these crops enhance the economic benefits of sludge application to private land.

Application of sludge in liquid form (5 to 7 percent solids) also may increase yields in the dryland areas. Although sludge application to legumes is not recommended, a light application of sludge in liquid form may benefit crop yields as a result of the added moisture.

In addition to nitrogen uptake or the ability to use high levels of sludge, another important factor in crop selection is the tolerance of crops to high levels of sludge application, which means the crop would have to be able to withstand water logging, salts, and heavy metals. These problems are more critical for public land than private. The rate of application that is most beneficial to the crops, and therefore to the farm operator, will not likely cause these problems unless the area is one of high yearly rainfall. High rainfall may lead to water logging or runoff problems.

High rates of sludge application to public land, where disposal has higher priority than the revenue of the crop, may increase these problems. Rates of application on any land need to be monitored for the build-up of heavy metals. If crops are to be taken from the land, heavy metal concentrations must be controlled. If heavy metal concentrations become excessive, then use of the land for crop production may have to be discontinued. This would entail additional land purchases by the sewerage agency.

The seasonal growth or dormancy for the alternative crops determines when application will be possible. In areas when land is cropped every year, it may be necessary to leave some land fallow for sludge application during the critical growing periods. In areas where land is cropped once every two years, this problem should not arise. However, additional weed control practices may be required. Weed growth on fallow land is increased by the nitrogen in sludge.

State regulations occasionally restrict the cropping alternatives. In Oregon, the Department of Environmental Quality has prohibited the use of liquid digested sludge "as fertilizer on root crops, vegetables, low growing berries or fruits that may be eaten raw. Application of sludge shall not be made to the land later than one year prior to planting where vegetables are to be grown" (3). Both animal and human health problems should be considered for feed and food crops. Further research into the health hazards associated with the application of sludge is needed.

### Selection of optimal application rate

Determining the optimal application rate centers on both cost and revenue considerations. Remember, however, that infiltration rates, percolation rates, loading factors, and the potential for pollution are also important considerations. The application rate is an important variable because it has a direct effect on land requirements.

In analyzing the decision process for determining the rate of application, revenue considerations are discussed first, then the cost issues. The revenue consideration is important to the Sanitary Authority (SA) because the sale of the agricultural crops can be used to help offset the costs of operating the system. Of course for the farmer, the revenue side is most important. The effect of sludge application on his crop revenues will determine (1) whether or not he is interested in taking or purchasing the sludge and (2) the amount he is willing to accept/purchase.

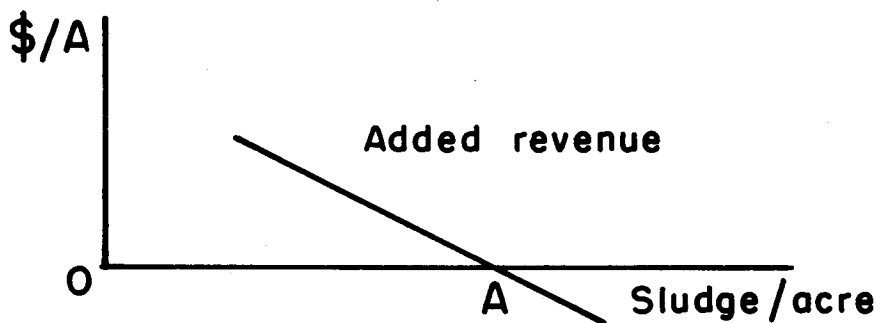
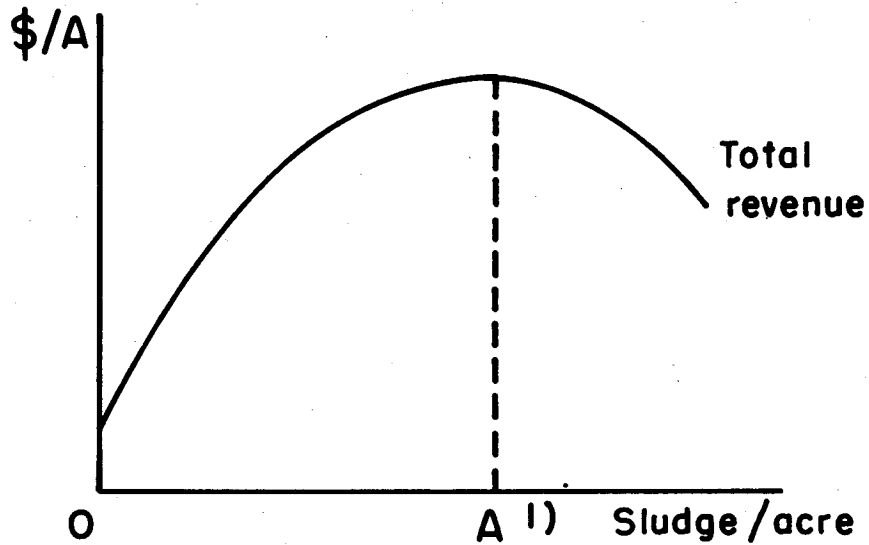
Figure 6 illustrates a hypothetical relationship between the sludge application per acre and the total revenue from crop production. As the sludge application per acre is increased, total revenue from crop production increases, reaches a maximum at Point A and then decreases. More research is needed to quantify this relationship and how the relationship is affected by alternative crops, soil types, etc. The work in Oregon indicates that there is considerable variation between crops grown (7).

The added revenue graph represents the change in the value of crop production associated with increments in the amount of sludge applied per acre. If sludge is made available to the farmer at no cost, it would be to his benefit to apply up to OA units of sludge. At Point A the maximum revenue per acre is obtained. There is no added revenue from an additional input of sludge. To apply more sludge per acre would require that the farmer be compensated for his loss in revenue.

Figure 7 illustrates the cost relationships involved in determining the optimal application rate. The total cost and added cost are both plotted as hypothetical relationships with the amount of sludge applied per acre. Note that as the application rate is increased the total cost increases but the added cost per unit of sludge applied decreases. The per unit cost savings associated with applying additional units of sludge per acre because of (1) a reduction in transportation costs from not having to haul for greater distance to apply to more acres of land, (2) lower requirements for moving and setting up handling and application equipment, and (3) additional land need not be acquired by SA's who own their application sites.

Figure 6.

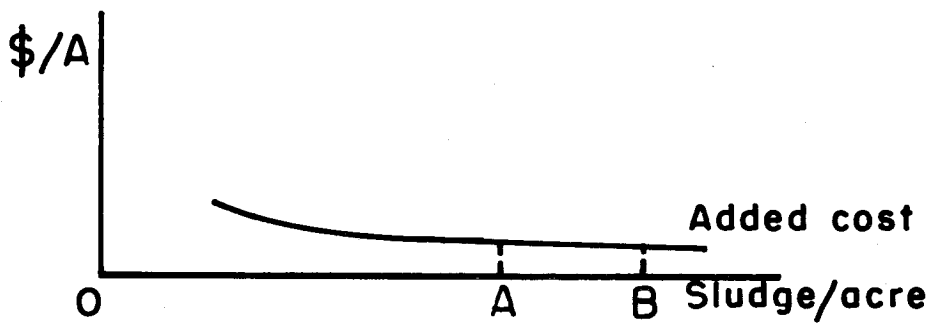
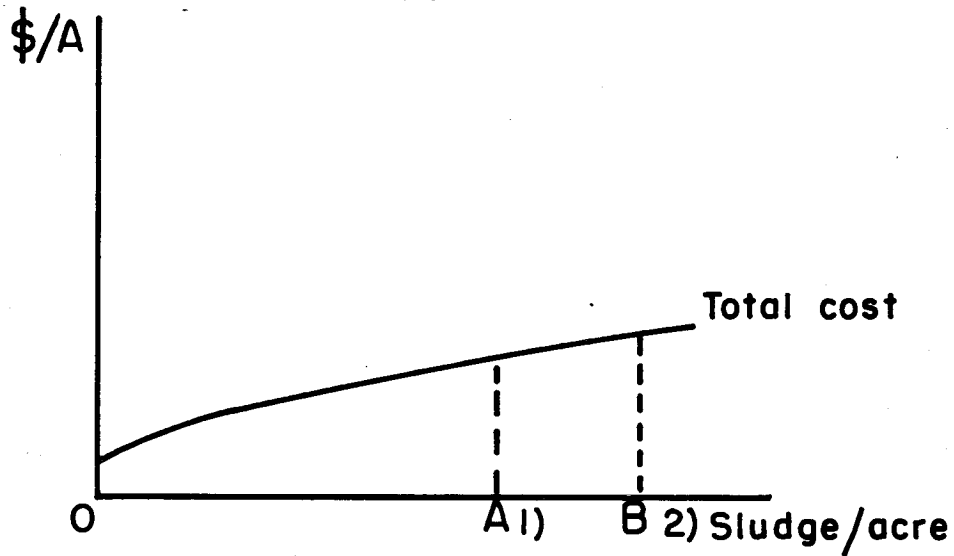
Total and Added Revenue per Acre Crop Production Related to Sludge Application.



*1) Point A represents the sludge application rate at which crop revenue is maximum.*

Figure 7.

Total and Added Cost per Acre  
for Sludge Delivery Related to  
Sludge Application.



1) Point A represents the sludge application rate at which crop revenue is maximum as shown in Figure 6.

2) Point B represents the sludge application rate at which there is a pollution hazard.

In the case where the SA is getting no revenues from the disposal of sludge, the incentive would be to apply the maximum amount per acre, up to Point B where there is a pollution hazard due to overloading (Figure 7). This is beyond the point of maximum crop revenue per acre, Point A. This follows from the relationship that as the application rate is increased, the total cost per acre for transportation, handling, and application increases but the added cost for each additional unit of sludge applied per acre is less.

In Figure 8 the cost and revenue aspects of this decision are put together. The optimal volume of sludge to be applied per acre then would be where the added cost of applying one more unit of sludge is equal to the added revenue. This Point C would be to the left of the point of maximum of crop yield and involves a lower rate of sludge application per acre.

This analysis has some implications for pricing sewage sludge, which are discussed in the next section. In the case where the SA is selling or delivering the sludge to private farms, the marginal revenue received by the farmer through the application of sludge would be considered. The recipient of the sludge is interested in the extra yield he can obtain by its use. He would be willing to pay up to the full value of the marginal increase in revenue to obtain the sludge so long as there is no risk involved. In some cases, however, the farmer may anticipate that the risk cannot be offset by the additional revenue and he will not pay for its use.

Some general points regarding physical considerations in determining application rates should be considered. Sludge should be applied so that the amount of available nutrients added to the soil does not greatly exceed the amount removed by the growing crop. Excess nutrients may leach into groundwater. Excessive nitrogen loading, salinity problems, and accumulation of heavy metals in the soil and growing crops are probably the greatest concerns to heavy and long-term applications. Heavy applications may cause nitrogen burn on hay, corn, and other crops because it covers the plant leaves, hampering respiration. The chances of nitrate toxicity to animals is also increased with heavy applications.

#### What Price for Sludge?

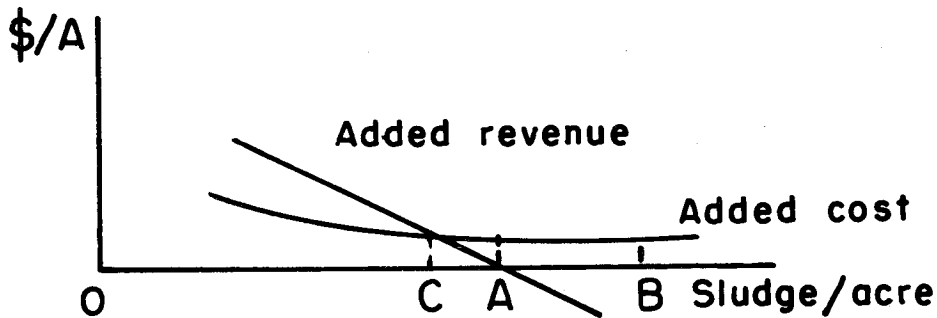
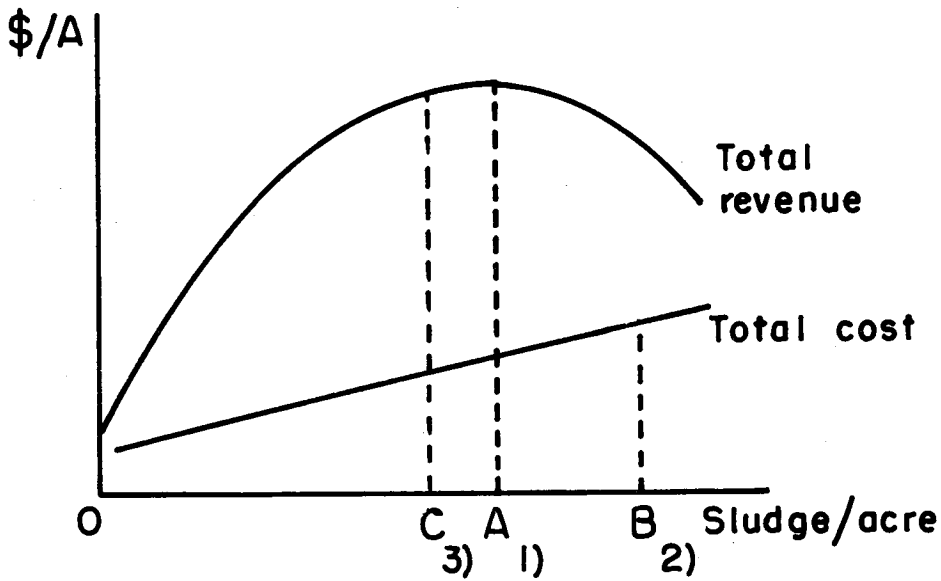
Depending on one's point of view, the value of sludge can be positive or negative. To the SA it has a negative price because of the cost involved in its disposal. On the other hand, sewage sludge contains organic materials, minerals, and water which do have value. With the increases in the prices of nitrogen and phosphorous commercial fertilizers over the past 3 years, farmers have become more interested in sewage sludge as a source of these materials. In addition to the fertilizer materials, sewage sludge has value as humus to improve soil fertility and soil structure. The water itself may have value as crop irrigation at certain times of the year.

An estimate of the value of sewage sludge to the farmer can be made by calculating the value of the fertilizers, minerals, and organic matter for which the sewage sludge could be substituted (Table 5). The sludge analysis used for this example was taken from data supplied by James Vomocil, Oregon State University Extension Soil Science specialist. Based on the prices of the fertilizers, minerals, and organic matter, the value per ton of dry sludge would be \$32. With 5 percent



Figure 8.

Total and Added Revenue per Acre  
for Cost Related to Sludge Application.



1) Point A represents the sludge application rate at which crop revenue is maximum as shown in Figure 6.

2) Point B represents the sludge application rate at which there is a pollution hazard.

3) Point C represents the optimal rate of sludge application, where added revenue is equal to the added cost.

Table 5. Example Content of Sludge on a Dry Weight Basis.

Component	Analysis <sup>1/</sup>	Amount per ton dry sludge	Price per pound <sup>2/</sup>	Value of component
	Percent	Pounds		
Nitrogen . . . . .	3.0	60	\$ 0.32	\$19.20
Phosphorus . . . . .	0.7	14	0.57	7.98
Potassium . . . . .	0.02	0.4	0.12	.05
Iron . . . . .	2.1	42	0.02	.84
Zinc . . . . .	0.4	8	0.12	.96
Copper . . . . .	0.02	0.4	0.20	.08
Sulfur . . . . .	0.5	10	0.09	.90
Organic matter . . . . .	50.0	1,000	0.002	<u>2.00</u>
Total value per ton (dry weight) . .				\$32.01

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Value per ton	
10 percent solids . . . . .	\$ 3.20
5 percent solids . . . . .	1.60
Value per 1000 gals.	
10 percent solids . . . . .	13.62
5 percent solids . . . . .	6.81

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<sup>1/</sup>Source: James Vomocil, Oregon State University Extension Soil Science Specialist.

<sup>2/</sup>Based on 1975 prices.

solids, the sludge would be worth \$1.60 per ton, and at 10 percent solids, \$3.20. The value per 1,000 gallons would be \$13.62 for 10 percent solids and \$6.81 for 5 percent solids. As a result of the valuable components in sewage sludge, farmers may be willing to pay to acquire sludge.

Pricing sludge can be a complicated process, in view of the great variability in the composition of sludge. Assuming that this composition is known, the price is determined through the interaction of supply and demand in the market place. Like other market prices, the price of sludge is subject to negotiation between the SA and the farmer(s) and the outcome of this negotiation will be determined by the relative bargaining position of the two parties. Within this framework, however, the upper and lower limits within which the negotiating process will operate can be specified.

At the upper limit, the value of sludge will be equal to the value of the commercial fertilizer that it displaces in the crop production process, adjusted for differences in sludge application costs. The farmer could play this value to obtain sludge so long as there is no risk or additional costs involved.

At the lower limit the price would be negative, i.e., it would be the cost to the SA of disposing of the sludge through land alternative treatment method, less the cost of delivering it to the farm.

The maximum price a farm operator is willing to pay for sludge will be affected by the changes in production practices. Application at rates meeting all nitrogen requirements may require additional field work to eliminate runoff problems if the sludge is 5 to 10 percent solids. Application of sludge to fallow land enhances weed growth, requiring increased efforts for control. Even if sludge is applied to crops, weed-control problems still arise. This is due to the time pattern of availability of the nitrogen contained in the sludge. Transportation and application cost must be considered. In addition, management time by the farm operator will be increased.

Some farmers are reluctant or unwilling to use sludge because of adverse attitudes from their neighbors and the risk of pollution. In fact, in some cases the perceived risk and attitudes against the use of sludge may require that the SA pay the farmer a token amount to entice him to utilize it. Even with this token payment, agricultural utilization may still be a more economical method of disposal than going to some other means, e.g., incineration.

#### Implementing the Sludge Utilization Plan: Some Guidelines

Decisions about the disposal of sewage sludge may affect a large number of people in direct ways. This is particularly true of a decision to apply treated sewage sludge to land. The major obstacle to a number of otherwise well-founded land application plans has been the unwillingness of the public to accept "some-one else's waste" on adjacent land.

Implementation of a plan to apply sludge to land may require a program of public education on the potential to the municipality, and a sludge-management program that insures proper safeguards. These safeguards must protect the public, cooperating farmers, and the municipality, and must provide a mechanism for feedback and evaluation of the program by affected parties.

Most professionals and federal officials concerned with land application programs recommend an extensive educational program before initiation of any land application plan (10).

Perhaps the strongest argument for a public information program has been made by two local officials involved with the large Muskegon, Michigan system of land application of sewage effluent (8):

"In looking back on the Muskegon project, with 20-20 hind-sight, we can see where a public relations firm or consultant should have been in on the ground floor to deal with the problem of getting the information on the entire project before the people, industry, and the politicians involved."

"The public relations team should have a hand in the early planning of the land acquisition and relocation policies and procedures. They should also have the responsibility for the conduct of public informational meetings to be held throughout the project area, as well as the more common use of the media."

"The question of removing public land from the tax roles was well-handled in the Muskegon project. It was a policy adopted in the early stages that a payment in lieu of taxes, based on a base-year valualional, would be made to the governmental unit within whose jurisdiction such land became county property. This payment would then continue to be borne by the system as an annual operation cost. This was of substantial help in overcoming the opposition of the townships and school districts of a substantial portion of their property tax base."

Most discussion of educational programs related to land application of sludge and effluent concern large projects.

While a massive education program on the health, odor, and tax aspects of a land-application proposal may be appropriate (or even necessary) for large systems involving the purchase of tracts of farmland, such a program may be inappropriate for less extensive projects. Information about land application and a municipality's program should be available to those requesting such information. A large public information effort about a small project, however, might be unjustified except in exceptional situations.

Most of the discussions of education programs have focused on providing information to the public. Unless the municipality presently owns all the land it will need for land application of sludge, however, the success of a land application program may depend on the willingness of nearby farmers to cooperate by accepting or purchasing the municipality's sludge for application to their farmland. Particularly in medium-sized communities with insufficient municipally-owned land for sludge application, a program of information for farmers about the potential benefits and risks of using sludge on farmland as fertilizer may be more important than an education program for the general public.

## The Sludge Management Program

A well coordinated sewage sludge management program is especially important if the sludge is to be applied on privately owned land.

### Management procedures

Criteria for site selection is an important component of the management program if suitable public land is not available. These should include such items as accessibility, crops grown, soil characteristics, topography, groundwater situation, etc. These criteria should be used to determine to which farms the sludge would be delivered. Pound and Crites (4) have developed criteria for selecting sites for the application of effluent which could serve as a starting point for sewerage agencies. The idea here is to develop a positive program for selecting which sites the SA will deliver to, rather than a first come-first service basis.

The coordination of application means considering the types of crops to be grown so the SA can plan ahead where it will be applying sludge during each of the upcoming months. In addition to a first choice, it is important to have an alternate application site as a contingency plan for disposal of sludge in case of weather changes, etc.

Considerable flexibility may be gained by allowing the farm operators to select the cropping patterns that are compatible both with sludge application and with the typical crops of the area. This allows the farm operator to adjust to changing product prices and reduces the costs of the sewerage agency. An agreement that includes sufficient acreage for sludge application throughout the year and constrains crop choice in a manner consistent with local health requirements is one approach.

Adequate supervision of application will help increase returns. If the sewerage agency accepts the responsibility of supervision, relations with the farm operator can be enhanced by ensuring rates of application that are consistent with crop nutrient requirements. This also includes the even distribution of the sludge on the land.

### Agreements with cooperating farmers

The application of sewage sludge to private agricultural land is a joint venture between the SA and the farmer. It involves certain characteristics important to success: clearly defined objectives; sound economic potential; well-defined responsibilities and management procedures; well-qualified management, and tolerance for disagreement.

Wherever possible, objectives, policies, and procedures should be put into writing and updated and modified regularly. It is important to provide procedures for arbitration in case of disagreements.

Written sludge utilization agreements should be negotiated with the cooperating farmers so that any future questions can be answered by referring to the original document.

The following points have been discussed at various points in the text. However, they bear repeating because of the considerations they deserve for coverage in any written agreement.

Length of time of contract. This is important to the farm operator. The longer the contract, the more likely the farm operator will be willing to make investments that may be crucial to successful sludge application. The sewerage agency also gains from longer contracts. A contract life of between 5 to 15 years probably will provide enough flexibility for the SA to adjust to future events and yet provide the stability preferred by the farm operator.

Management. The importance of good management by both the farm operator and the SA cannot be over-emphasized. Poor management by the farm operator leading to pollution of either surface or groundwater may effectively ruin an otherwise satisfactory disposal agreement through ill-will on the part of the public. Adequate monitoring of application rates and even distribution requires good supervision. These are important in maximizing returns.

#### Feedback and evaluation

There is need for a system of information feedback and evaluation. The composition of the sludge must be known; the environmental effects need to be monitored. Continuing information is needed regarding public reaction. The SA may want to conduct research to evaluate the effects of sludge application on crop production with different types of crops and application rates.

It is important to identify problems as they are encountered, if not before, and provide for their speedy resolution. This involves developing a system for information feedback from the cooperating farmers, SA employees, and residents of the area.

#### Conclusions

The land application of treated sewage sludge is not appropriate for every situation and certainly is not a panacea for water pollution problems in Oregon. It is, however, one of several alternatives which communities are required to consider in applications for federal assistance under the 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500). It is one which both sewerage agencies and farmers may find attractive in times of high fertilizer prices.

Research is needed to determine among other things, the crop responses to sludge, potential for health problems associated with agricultural use of sludge and the tolerance of soil to heavy metal concentrations often found in sludge (7).

In making decisions among the various alternatives for sludge utilization, municipalities must weigh the costs and benefits of the various options.

## APPENDIX

### Information Required for Determining Capital<sup>1/</sup> Investment Requirements and Operating Costs.

#### Investment Outlays

#### Capital investment required for centrifuges

$$S_c = V_{\text{MGD}} \times \frac{10\text{Hp}}{\text{MGD}}$$

$$K_c = \frac{(18.62 \log S_c - 32)1000}{S_c}$$

$$T_c = K_c S_c + A_E$$

Restriction: 10Hp  $S_c$  250Hp

$S_c$  = Total power capacity of the centrifuge in horsepower.

$V_{\text{MGD}}$  = Volume of sewage in millions of gallons per day received by the sewage plant which the centrifuge is designed to serve.

$K_c$  = Cost of the centrifuge per unit of horsepower.

$T_c$  = Total cost of the centrifuge and auxiliary equipment.

$A_E$  = Cost of auxiliary equipment

$\text{Hp}$  = Horsepower.

#### Truck investment

The initial outlay for trucks (either dump or tank) depends on the price per new truck and the number of trucks required. The number of trucks required depends on (1) the volume of sludge to be applied; (2) distance between the sewage plant and application site; (3) truck capacity; (4) the number of days trucks will operate; (5) average truck speed; and (6) the number of operating hours per day. Item numbers 2, 5 and 6 are used to determine number of trips per day. Items 1, 3 and 4, along with trips per day, are used to determine the number of trucks required.

<sup>1/</sup>These computational methods have been taken from Kasper, et. al. (2). They are listed here to indicate some of the costs that should be included as well as for determination of total costs.

Calculations of the number of trucks required may result in a fractional number. The fractional part of a truck required may be covered through overtime or truck rental.

### Capital investment in pipelines

The investment outlay will include (1) construction costs of pipeline, (2) easement right-of-ways, (3) total cost of pumping stations, (4) landscaping costs, and (5) engineering and legal fees.

Pipeline costs include the trench, landscaping, purchase and laying of the pipe. The cost of easement involves payment for the easement, appraisal fees, negotiating costs, surveying, and court costs. Pumping station costs include both station and pump costs. Engineering and legal costs usually are based on a percentage cost of the pipeline contract.

### Storage tank investment

The size of tank required will depend on the volume of sludge processed per year, the maximum number of consecutive days sludge would have to be stored, and the construction costs per unit volume. The number of consecutive days of storing will depend on when sludge can be applied to the soil.

### Fixed Operating Costs

The most common fixed costs are depreciation of capital equipment used and interest on the capital investment. However, there are some costs associated with trucks that may be considered as fixed costs. These costs include vehicle registration, insurance, and salaries.

Besides depreciation and interest, the fixed cost for the pipeline includes a maintenance charge for the pumping stations and a salary charge. In Table 3, depreciable capital for the pipeline includes only construction costs, pumping station investment and engineering fees.

Administration fixed costs include depreciation on the building, interest on total capital investment and salaries of office personnel (engineer, secretary, etc.).

The only fixed costs for a centrifuge are interest and depreciation.

### Variable Operating Costs

Variable costs for dewatering equipment will include operation, servicing, and repairs.

Variable truck costs include fuel, oil, repairs, servicing, tires and tubes. The total costs for trucks will depend on average mileage for the trucks per day,



the number of days sludge is transported, and the number of trucks employed.

Variable costs for the pipeline include power costs and pump maintenance. Power costs are determined by volume, total friction headloss, and electricity costs.

Variable costs for storage have not been included in Table 3. However, charges need to be estimated for maintenance and repairs of storage tanks.

Note that application costs are not listed in Table 3. These costs will have to be considered if the sludge is applied to publicly-owned land, or if disposal on privately-owned land is conditioned by public ownership of application equipment. Unless otherwise specified, application labor also should be included.

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