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COST OF FOREST LAND DISPOSAL OF SLUDGE

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COST OF FOREST LAND DISPOSAL OF SLUDGE

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ABSTRACT

COST OF FOREST LAND DISPOSAL OF SLUDGE

By

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This study was designed to help answer some of the economic questions regarding application of sludge to forest land. The technologies available for application are described, their costs calculated, and the sensitivity of the costs to changes in key variables is tested. A discussion of prevailing public attitudes toward land application of sludge is also presented, along with some speculation on the role of public opinion in choosing any land application option and some suggestions on how waste managers can deal with interested groups.

A simple simulation model is used for the cost estimation. The model, called SLUDGE, calculates the costs of sludge disposal by various methods. The cost associated with any disposal method chosen consists of four components: transportation, land application, groundwater monitoring and nonquantified costs (public relations). SLUDGE calculates transportation, application, and monitoring costs.

Major conclusions of the study are: (1)sludge transportation is usually the largest component of disposal cost; (2) for any mode of transportation, increasing haul distances causes transport costs to escalate more rapidly than any other variable testes; (3) rail and barge transport costs are fairly competitive with each other and are better suited to handle long-distance transport of medium to large sludge volumes than trucks; (4) pipeline transport of liquid sludge is most cost-effective, though least flexible, means of moving

large volumes of sludge long distances; (5) spray irrigation is a cheaper liquid sludge application method than either surface or subsurface vehicular application; (6) and, transportation and application of dewatered sludge are less expensive than transportation and application of liquid sludge, on a per-dry-ton basis. The cost of dewatering sludge must be weighed against this disposal cost advantage.

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SUMMARY AND CONCLUSIONS

The latest environmental movement, in the 1960's, left Americans with at least one enduring legacy. That is the existence of several institutions whose purpose--sole or otherwise--is to keep human exposure to toxic or disagreeable substances within acceptable limits. One of the areas of greatest concern was and will be water pollution.

There are many sources of water pollution. One of the major sources is waste disposal. Concern over pollution stemming from waste disposal has prompted, within the last ten years, a great deal of legislation aimed at controlling the environmental consequences of waste disposal. Some widely-used methods formerly employed to get rid of waste are no longer legal or economical, or will become illegal or uneconomical in the near future. Under the new regulations, waste managers are being encouraged to recycle their wastewater and sludge, particularly on land. Specifically, the use of forest land, parks, or other land not used for the production of food chain crops is advocated.

Before any disposal option is chosen, however, it must be economically attractive. The cost of forestland sludge disposal must be in the same ballpark as costs of other options if waste managers are to consider forest land disposal. At present, only 5 percent of the nation's sludge is disposed of on non-crop-producing land; even less on forest land specifically. The technology, economics, and acceptability of forest land disposal is not well established. So, while

EPA and other state or federal agencies recommend use of forests for sludge disposal, waste managers are waiting for information on the feasibility of such an option.

This study was designed to help answer some of the questions regarding application of sludge to forest land. Specifically, some of the technologies available for application are described, their costs calculated, and the sensitivity of the costs to changes in key variables is tested. Because management of response to public opinion can greatly add to waste disposal costs, a discussion of prevailing public attitudes toward land application of sludge is also presented, along with some speculation on the role of public opinion in choosing any land application option and some suggestions on how waste managers can deal with interested publics.

To present the costs, a simple simulation model is used. This model, called SLUDGE, calculates the costs of sludge disposal by various methods. The cost associated with any disposal method chosen may be grouped into four components:

Transportation

Land Application

Groundwater Monitoring

Nonquantified costs: Public Relations

Site Specific Costs

SLUDGE calculates expected transportation, application, and monitoring costs of different disposal methods, based on input prices selected by the user. All the nonquantified costs are site specific, in the sense that they may take different values in different situations. Public relations is treated separately due to the fact that public attitude is a critically important factor in determining the feasibility of land application of sludge. If land application is chosen as the disposal method, public relations will probably be required, though the magnitude of the effort will depend on the specific local situation.

The specific land application methods chosen for use in the SLUDGE model are shown in Figure 1. Tables 1 and 2 present a summary of representative costs calculated by the model. In general, the following conclusions are reached by the study:

1. Sludge transportation is usually the largest component of disposal cost.
2. For any mode of transportation, increasing haul distance causes transport cost to escalate more rapidly than any other variable tested.
3. Rail and barge transport costs are fairly competitive with each other. Neither is as flexible as trucking with respect to destination, but both are better suited to handle long-distance transport of medium to large sludge volumes than trucks.
4. Pipeline transport of liquid sludge is the most cost-effective means of moving large volumes of sludge long distances. It is also the least flexible mode, with respect to destination,

Figure 1. Quantified Cost Components in SLUDGE Model.

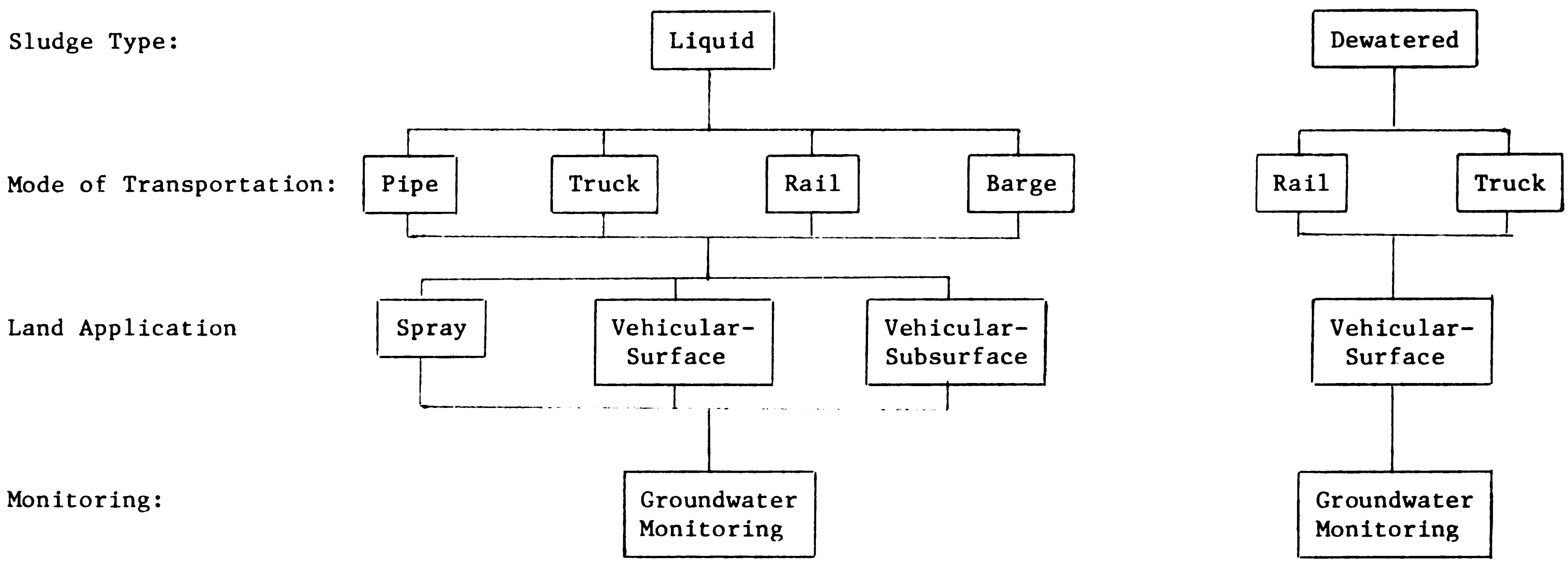

Table 1. Representative Sludge Disposal Cost Summary, Liquid Sludge Type[1/]

Cost Component	Sludge Volume, mg[2/]	Application Method		
		Spray	Vehicular-Surface	Vehicular-Subsurface
		(annual costs in dollars per dry ton of sludge)		
Transportation[3/]	50	$ 8.29-832.77[6/]	$ 8.29-832.77	$ 8.29-832.77
Application[4/]		7.28- 8.54	16.62- 16.87	16.90- 17.14
Monitoring[5/]		.91	.91	.91
Total		$16.48-842.22	$25.82-850.55	$26.10-850.82
Transportation	250	1.93-482.83	1.93-482.83	1.93-482.83
Application		7.26- 8.53	16.43- 16.68	16.71- 16.96
Monitoring		.18	.18	.18
Total		$ 9.37-493.54	$18.54-499.69	$18.82-499.97
Transportation	500	1.11-403.40	1.11-403.40	1.11-403.40
Application		7.25- 8.52	16.33-16.58	16.62- 16.87
Monitoring		.09	.09	.09
Total		$ 8.45-412.01	$17.53-420.07	$17.82-420.36

Table 1 (cont'd.).

1/ Base, or 1979, prices only are represented in this table.

2/ Million gallons.

3/ The transportation costs represent the range of lowest to highest cost calculated by SLUDGE, assuming no loading-unloading facilities are needed. The cost ranges are associated with changes in transportation distance (5 to 320 or 20 to 320 miles, one way, depending on sludge volume) and mode of transportation (truck, rail, barge, and pipeline).

4/ Application costs, for each method, vary by soil loading rate (from 2.5 to 10 dry tons per acre).

5/ Assumes 3 monitoring wells are required.

6/ In most cases, the lower cost figure is for short-distance (20 mile) pipeline transportation; the high number for long-distance (320 mile) rail or barge transportation.

Table 2. Representative Sludge Disposal Cost Summary, Dewatered Sludge Type[1/]

Cost Component	Sludge Volume, cu. yd.	Annual Cost
		(per dry ton)
Transportation[2/]	50,000	$ 5.25-59.36[4/]
Application		5.60
Monitoring		.82
Total		$11.67-65.78
Transportation[3/]	250,000	10.55-59.35
Application		3.95
Monitoring		.16
Total		$14.66-63.46
Transportation[3/]	500,000	10.55-58.03
Application		3.95
Monitoring		.08
Total		$14.66-62.14

[1/]Base, or 1979, prices used to calculate costs.

[2/]Transportation cost varies by haul distance (5 to 320 miles) and mode of transport (truck and rail).

[3/]Transportation cost is only for rail haul; range presented is associated with changing haul distance (20 to 320 miles).

[4/]The lower cost figure is for very short distance (5 mile) truck transportation; the high cost figure for long distance (320 mile) rail haul.

and will probably have to be combined with another transportation mode in any practical system.

5. Spray irrigation is a cheaper liquid sludge application method than either surface or subsurface vehicular application. Subsurface application is only slightly more expensive than surface vehicular application, and may be much more effective in minimizing possible adverse public reaction. However, subsurface vehicular application may not be feasible on many forested sites without substantial soil preparation.
6. Groundwater quality monitoring is not a costly proposition, particularly in view of the protection against claims of pollution or nuisance that a well-designed monitoring system provides. The initial cost of monitoring--e.g. during the first stages of the disposal system implementation--may be much higher than normal monitoring operation, particularly if sites can be re-treated.
7. Transportation and application of dewatered sludge are less expensive than transportation and application of liquid sludge, on a per-dry-ton basis. The cost of dewatering sludge must be weighed against this disposal cost advantage.
8. In general, public attitudes toward land application of sludge are at least mildly negative, and in some cases have become strongly disapproving. Adverse public reaction is particularly strong when the people living near the disposal site feel geographically and politically removed from the municipality which constitutes the production area.
9. Public reaction does not have to stop land application schemes,

> but it must be recognized as a major factor in any disposal operation and given the same serious attention as the engineering or purchasing.

At present, forest land application of sludge is being encouraged by regulatory agencies. Some widely used sludge disposal options, like ocean dumping, are now being phased out. Still others, like agricultural land application, are viewed with guarded optimism, and their future is still in doubt. However, while forest land application is more attractive than many options from a regulatory standpoint, it will not be adopted unless it is financially competitive with other options. This study does not attempt to compare options, since actual sludge disposal costs depend to a great extent on local conditions, such as availability of labor or fuel, access to different forms of transportation, and proximity to forest or agricultural land. The study was designed to provide information on some of the major, quantifiable costs of sludge disposal on forest land, such that comparisons between options can be made.

INTRODUCTION

The environmental movement of the nineteen sixties and early seventies has produced, among other things, several programs whose major intent is to clean up America. Like everyone else, Americans are bound by the fundamental law that matter can neither be created nor destroyed. It can, however, be transformed and transported, and can thereby concentrate in undesirable form or amount. By the middle sixties the buildup of stuff, both products and wastes, had apparently reached such a magnitude that waste became a problem. The accumulation of waste in the air and water and on land received particular attention and many measures were taken to eliminate or control these waste buildups.

These measures usually consisted of legislation and its accompanying regulation. Since 1972, the list of regulatory restrictions on waste disposal has lengthened considerably, resulting in a narrowing set of disposal alternatives whose costs have escalated rapidly. Managers of municipal or agricultural wastes still have several options to choose from. Some are "cleaner" or "safer" than others, and there is some incentive for waste managers to choose the safest option available in order to avoid the consequences of pollution. There is also considerable pressure on both municipal and private waste managers to keep disposal costs down. Unfortunately, the "safest" methods are not always the cheapest.

The primary objective of the waste manager is to dispose of the

wastes. He is constrained by his institutional/legal and financial situation. Thus, he must not only get rid of the sludge produced, but disposal should be carried out in accord with existing statutes and regulations at the lowest cost attainable. At the present time, it is also advisable to plan waste disposal operations which can be continued indefinitely. The EPA and the States are still in the process of deciding how sludge can be disposed of so that some options that exist now may not exist in a few years. For example, ocean dumping, scheduled to cease by the end of 1981, is not a long-run solution to sludge disposal problems. Incineration of sludge may also be infeasible in the long-run in cities that expect to have or are now facing air pollution problems. The Clean Air Act Amendments identify wastewater treatment plants as potential point sources of pollution, a designation which may affect whether or not sludge can be incinerated. Since 25 percent or more of the sludge produced in America is presently incinerated, this restriction may be of major concern to waste managers (Metcalf and Eddy, 1978, and EPA, 1976a).

Presently the most promising alternatives available to help solve long term sludge disposal problems are incineration (where air pollution is not a limiting factor), sanitary landfilling, land application, strip mine reclamation, pyrolysis, and recycling of treated sludge or compost as a soil conditioner. The costs associated with each of these alternatives vary, depending on the amount of sludge produced and its constituents, availability and cost of land, equipment, facilities needed for disposal, and ultimately on the willingness of the public to accept the disposal practice. These factors all enter into the waste manager's decisionmaking process as he searches for ways

to get rid of his sludge without exceeding his budget, disturbing the public, or breaking the law.

Presently, sludge disposal on forest land is being advocated as a relatively safe, economical option. Forests are not generally used to produce food or forage, reducing the risk of the toxic or noxious elements in sludge reaching people through dietary exposure. Of course, there are still avenues for dietary exposure if forest land is treated (e.g. eating berries, mushrooms, or game from treated areas) but these risks are not quantifiable presently. In addition, forested areas are generally sparsely populated, further reducing potential health risks of waste recycling. Other factors which make forested land more suitable for waste recycling are "...superior soil infiltration properties, lower site acquisition costs, and favorable soil temperatures, allowing year-round wastewater application" (Metcalf and Eddy, 1978).

There are some drawbacks to forestland sludge disposal as well. One of the major questions which must be answered satisfactorily before any large-scale movement toward forest land waste application is begun concerns the costs of the recycling operation. It is apparent from waste processing and handling literature that the primary goal of the waste manager is not recycling but disposal. The manager will choose the disposal option which costs the least, considering all costs. The EPA regulations and national and state legislation encourage land application as an environmentally "safe" means of recycling sludge and waste-water, but only when such methods are economically and institutionally competitive with other acceptable options will such recycling take place.

Unfortunately, there are only a few studies and/or documented cases of costs of forest land application of sludge which can be used for such comparison of alternatives. There are many models and cases which show wastewater recycling costs, but little of the information is useful in estimating costs of sludge disposal. Few documented cases and even fewer models are available, and what information does exist is usually limited to a fairly narrow set of geographic, financial, or technological conditions.

One available model estimates the costs of land application of sludge. This model, called a "Procedure for Estimating the Cost and Investment Required for Sludge Recycling Through Land Disposal," was put together by a team of people at the New Jersey Agricultural Experiment Station at Rutgers University (Kasper, et al., 1973). It examines five activities: dewatering, transportation, storage, application, and plant uptake of nutrients contained in sludge.

The Rutgers model was designed with application to pasture or rangeland in mind, and specifically for New Jersey. Therefore, barge and rail transport of sludge were not considered. The transportation options included were truck (dump truck haul for dewatered sludge and tank trunk transport for liquid sludge) and pipeline transport.

The Rutgers model offers several application choices, all suited to unforested pasture or rangeland. The application alternatives include plowing and covering, contour furrowing, subsoil injection, and two forms of spray irrigation (from a tractor-trailer, or from a fixed pipe system) for liquid sludge, and plowing-furrowing or contour furrowing for dewatered sludge.

The Rutgers model does not include monitoring costs, but does

include the use of planted grass to utilize the nutrients in sludge. Only one transportation distance--20 miles, one way--was used, and no sensitivity tests were performed to determine how changes in component or input costs could affect the total cost of land disposal. The Rutgers model does not treat the individual activities separately, but combines various methods of transport, dewatering, application, and recycling into five alternative total sludge-disposal systems.

The Rutgers model is useful, but limited. For example, the application technologies it includes are not particularly suitable for forest land sludge disposal operations. Moreover, it is not adaptable: it cannot be made to simulate costs for situations not closely resembling the five alternatives examined. Nor is it capable of examining the impact of changes in volatile or important variables like the cost of fuel, equipment, or labor.

There is one case study which pertains specifically to forest land application of municipal sludge. It is being conducted by the University of Washington Center for Ecosystem Studies. The study, begun in 1973, was to evaluate the feasibility of applying dewatered sludge from the city of Seattle to the University's Pack Forest. The latest progress report (Edmonds and Cole, 1980) includes a discussion of costs of forestland application and, interestingly, benefits (in terms of the value of tree growth attributable to the addition of nutrients in sludge). Though benefits are not explicitly a part of this study, it would be a mistake for the decisionmaker not to consider them, if they exist and can be reaped.

Like the Rutgers model, the Washington study is of limited usefulness in making general comparisons between forest land disposal and

other alternatives. The technology employed is specifically adapted to Washington conditions--e.g. steep slopes, fragile soils, and existing young-to-mature conifer stands. Insofar as this information exists for the type of forest used in the Washington study, the information presented in this document will not attempt to duplicate it.

STUDY OBJECTIVE

This study is designed to provide information about some of the economic and policy issues associated with land disposal for land treatment of sludge. Its purpose is to provide an indication of sludge disposal on forest lands. The specific objective is to determine the costs of alternative feasible methods of disposal.

Since these costs are not verifiable from existing field experience (which is practically nonexistant), key components of sludge disposal cost are varied via computer simulation in order to determine their effect. Key cost areas investigated are transport, application and monitoring costs.

Sludge is the residue left over when wastewater is purified. Over 5 million dry tons of municipal sludge are produced each year (EPA, 1976a). If secondary treatment of wastewater is required, the volume nearly doubles. Forty percent of the volume presently produced is either dumped in the ocean or incinerated.

Both of these practices (ocean dumping in particular) are unreliable as long-term solutions to the sludge disposal problem. Land application is an alternative that offers promise as a long-term solution, if properly managed and adapted to local conditions. As of 1976, only about 5 percent of the sludge produced in the U.S. was applied to non-crop-producing lands, only a small portion of which was disposed of on forest lands.

As noted earlier, land application processes include transportation, application (including short-term storage of sludge), and monitoring of groundwater and surface water runoff.

There are four principal ways of transporting sludge--truck, railroad, barge or pipeline. The method chosen and its cost depends on the solids content of the sludge, the terrain separating the wastewater treatment plant and the disposal site(s), and the distance between plant and site(s). There are also different ways of applying sludge to land. Again, the choice of method and its cost depends on the solids content of the sludge and site characteristics. The proximity of the disposal site(s) to human habitation may also play a role in determining which application method is used.

Storage of sludge over long periods is normally not a part of the land application operation. However, short term storage may be necessary to allow for temporary vagaries of weather or site condition. This is usually a simple process; it may involve no more than leaving a loaded trailer at the disposal site until the sludge can be applied, usually in a matter of a few days. Short term storage is considered part of the application process for purposes of cost analysis.

The primary purpose of monitoring is to check for groundwater pollution. Contamination of surface runoff may not be a problem on properly managed sites. Some checking may be necessary to insure that pollutants are contained at the site, but this is usually a matter of proper site selection and application system design.

These three processes--transportation, application, and monitoring--and some of the alternatives available for accomplishing them are described in following sections. Discussions of types of equipment available, labor requirements, and operating characteristics of each system are included.

To summarize, the overall cost of the land application process depends on the choice of transportation and application methods, the need for short-term storage, transportation distance, amount and type

of sludge involved, wages, equipment characteristics, fuel price and monitoring requirements. The effects of these and other variables on the total cost of land application are discussed, and the sensitivity of system costs to changes in these variables is explored.

The total cost of forest land application of sludge also depends on the cost of getting and maintaining public acceptance of the operation. Land application of any sort often carries a negative connotation, particularly in the United States. As a result, some waste managers hesitate to implement land application for fear of inviting public disfavor or being involved in costly litigation.

Negative public reaction is usually only a problem where large quantities of sludge are involved, and particularly where the residents near the disposal sites do not consider themselves part of the area where the sludge is produced. The history of attempts to implement land application of sludge in areas outside the area where the sludge is produced is short, and each case is unique in some important respects. Thus, while costs of overcoming public opposition to land application may not be quantifiable, it is useful to identify sources of potential public relations problems.

STUDY SCOPE AND LIMITATIONS

This study focuses on land application, with special emphasis on forest land application, for two reasons. First, forest land application is presently a promising alternative for solving sludge disposal problems, given the state of regulatory opinion and direction on waste disposal. Second, less is known about the economics of land application than is known about many other methods, such as incineration, landfilling, lagooning, and recycling (EPA, 1975).

This study is also limited to discussion of sludges which are not considered hazardous wastes. This includes, at present, most sludge. It excludes industrial sludges which have higher concentrations of heavy metals or toxic persistent organics like polychlorinated biphenyls (PCBs) or certain pesticides and pesticide residues. In its regulatory activities in solid wastes, EPA also treats hazardous waste disposal separately from sludge disposal (EPA, 1980). Other materials not treated like sludges by Federal regulatory agencies are also excluded. Excluded materials are: agricultural manures and crop residues, mine residues intended for return to mine sites, untreated domestic sewage, solid or dissolved materials in irrigation return flows, nuclear wastes, industrial discharges identified as point sources of pollution, and solid waste which is disposed of by underground well injection.

The technology of forest land application of sludge is not well developed, as noted previously. Limited experience, however, has shown that there are application methods which can be successfully adapted from agricultural processes. These methods include the use of moveable spray guns or high flotation vehicles. Since they have been shown to be feasible, application cost calculation is limited to these technologies.

Sludge disposal problems are seldom encountered unless there is an appreciable volume of sludge requiring disposal. A survey of municipalities using land to dispose of sewage sludge (EPA, 1977b) indicates that small amounts of sludge can be cheaply disposed of without investing in more costly land application systems. Often, simply allowing farmers or other residents to haul away sludge for crop, garden, or home use is sufficient.

Accordingly, the costs presented here are not intended to apply to sludge volumes smaller than approximately 7,000 dry tons per year (5 million gallons of liquid sludge)[1/].

Very large sludge volumes may also present problems which are not easily dealt with. Forest land disposal systems described in this study have not yet been applied to sludge volumes typical of major municipal systems. The information that exists (Sheaffer and Roland, Inc., 1978) represent special cases, with different conditions than would normally pertain. However, this is probably appropriate. A municipality or agency which has 500,000 cubic yards of sludge to dispose of will need at least 7500 acres annually to apply it to and even if we assume that the same areas can be retreated, this may be out of the question for any length of time. Unless much higher loading rates are used, land disposal may not prove practical when very large sludge volumes are considered.

[1/] However, the model can be used to calculate costs of land disposal of small sludge volumes, if desired.

Since it was impossible to define a "typical" site on the basis of very limited operational experience, it is assumed that the forest site itself is not incompatible with sludge application--that is, any site chosen would be fairly well-drained, not overly steep or rocky, not immediately adjacent to surface water--and would have reasonable access. If this type of site is available within a reasonable distance of the source of sludge production, the SLUDGE model may provide a fair representation of expected costs (except where the annual sludge volume is very small and reassignment of resources and use of existing or used equipment is not feasible, or other disposal technologies are more suitable). If such a situation does not exist, the waste manager has two options: he can consider other means of sludge disposal, or he can create suitable site conditions. This can significantly affect the monetary portion of sludge disposal cost.

There are other factors, encountered only in certain situations, which are similarly capable of adding to or subtracting from basic costs calculated in this broad a study. These factors include site modification (roading, clearing), the effect of site retreatment, and municipal treatment construction grants. They are treated in some detail in Appendix D.

STUDY METHODS

Quantifiable costs of land application of sludge are developed by use of a simulation model called SLUDGE. The model allows a decision maker to specify the magnitude of certain key variables and then calculates the costs of transportation, land application including short-term storage), and monitoring of groundwater quality. The model has as its variables those things which are subject to greatest changes or of greatest concern over times; including such things as the labor, fuel, and some equipment costs. Some model variables are specified at several representative levels. Other variables may assume any value.

This study is designed to provide guidelines on the economics and social context of forest land application of sludge. Its purpose is to provide indications of expected costs, not precise documentation. Cost figures presented in the text of this report should be regarded as pointing out what order of magnitude can be expected. Accurate representations of costs, based on experience, are preferable but unavailable. That being the case, the model presented here is used to simulate costs rather than document them.

SLUDGE: A SIMULATION MODEL

Modeling is a useful approach for dealing with application related costs. The expenditure associated with purchasing, operating, and maintaining all the inputs necessary to dispose of sludge on forest land are fairly straight forward. It is this type of cost that SLUDGE is used to estimate.

Disposal of sludge on forest land incurs, as noted previously, two kinds of monetary costs--public relations and application related costs. "Public relations" is the term applied here to the cost associated with gaining and maintaining public acceptance of the disposal operation. Experience with land application of sludge has shown that public attitudes can be a pivotal factor in many types of disposal operations. Public relations costs are largely determined by the social and political situation of the area in question, and as such are too site-specific to be included in a structured model.

Sludge is a simple simulation model which calculates the cost of transporting and applying sludge to forest land and monitoring the groundwater at the disposal site. Any forest land sludge disposal operation will include these elements.[1/]

The total disposal cost will depend on what it costs to carry

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[1/] Monitoring is not specifically required, but strongly advised. New interpretations of existing legislation may make monitoring a requirement in the future; in any case, it is well worth the effort to assure that no groundwater pollution is taking place.

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out these three activities. The cost of each activity, in turn, depends on a number of things, some of which will vary considerably from operation to operation. Since SLUDGE is not a site specific model, some of the more volatile elements which determine disposal costs are treated as variables, which may assume any value. Examples include transportation model and distance, application equipment cost, and the interest rate. Other elements are fixed within the model. Such elements include operation and maintenance requirements for transportation facilities and application equipment, loading and unloading times for application vehicles, and the solids content of liquid and dewatered sludge. Figures 2 to 4 illustrate the SLUDGE model, and specify which elements are variable and which are fixed.

A general discription of how SLUDGE works follows. Methods used to arrive at transportation, application, and monitoring costs are explained along with descriptions of the technologies used. Quantitative estimates of these costs appear in Chapter 4.

Nonquantified costs, while not included in the SLUDGE model, may be very important. Though it is impossible to estimate their magnitude without reference to a particular situation, these costs must be considered in planning a forest land sludge disposal system. Accordingly, discussion of these costs is included.

Figure 2. *Transportation System:* Fixed and Variable Elements of SLUDGE Model

Mode	Elements		
	Fixed Elements[1/]		Variable Elements
Truck	Sludge type	Liquid and dewatered	Sludge volume
	Loading facilities	With and without	Fuel price
	Distance	5, 10, 20, 40 and 80 mi.	Labor wage
	Truck size	2500 and 5500 gallon[2/]	
		15 and 30 cubic yard[3/]	
Barge	Sludge type	Liquid	Sludge Volume
	Loading facilities	With and without	Tug billing rate
	Distance	20, 40, 80, 160, and 320 mi.	
	Barge size	500,000 gallon	
	Tug size	2,000 h.p.	
Rail	Sludge type	Liquid and dewatered	Sludge volume

Figure 2 (cont'd.).

	Loading facilities	With and without	
	Distance	20, 40, 80, 160 and 320 mi.	
	Tank car size[4/]	20,000 gallon tank[2/]	
	Train size[4/]	10, 20, and 100 unit tank	
Pipe	Sludge type	Liquid	Sludge Volume
	Pipe size[4/]	6, 10, 14 and 18" diameter	
	Distance	5, 10, 20, 40, 80, 160 and 320 mi.	

[1/]Magnitude or description shown to the right of fixed element identification

[2/]Liquid sludge

[3/]Dewatered sludge

[4/]Each size applied to its practical limits.

Figure 3. Land Application System: Fixed and Variable Elements of SLUDGE Model.

Method	Elements		
	Fixed Elements		Variable Elements
Spray Irrigation	Sludge type	Liquid sludge	Sludge volume
	Equipment unit	Rain gun, trash pump, 600' pipe	Equipment price
			Land price
			Equipment life
			Soil loading rate
			Labor wage
			Storage construction cost
			Fuel price
			Interest rate
Vehicular Surface Application	Sludge type	Liquid and dewatered sludge	Sludge volume
	Vehicle size	1500 gallon tank[1/]	Land price
		7.2 cubic yard bed[2/]	Equipment price

Figure 3 (cont'd.).

		1.5 yard front-end loader[2]	Soil loading rate
			Labor wage
			Storage construction cost
			Fuel price
			Interest rate
Vehicular Subsoil Application	Sludge type	Liquid sludge	Sludge Volume
	Vehicle size	1500 gallon tank	Land price
			Equipment price
			Soil loading rate
			Labor wage
			Storage construction cost
			Fuel price
			Interest rate

[1] Liquid sludge
[2] Dewatered sludge

Figure 4: Groundwater Monitoring System: Fixed and Variable Elements of the SLUDGE Model

Elements	
Fixed Elements	Variable Elements
None	Number of wells
	Well depth
	Drilling cost
	Groundwater sample analysis cost
	Number of annual tests
	Labor wage

DESCRIPTION OF SLUDGE DISPOSAL SYSTEMS

Two types of sludges are examined: liquid and dewatered. Liquid sludges usually average 4-5 percent solids and within this range, changing solids content does not significantly affect disposal cost (EPA, 1977). However, in general, the higher the solids content, the lower the sludge transportation cost. Dewatered sludge is typified by vacuum filter cakes or some lagooned sludges (Metcalf and Eddy, 1978). For purposes of analysis, 20 percent solids is used as an average figure for dewatered sludge, and 4 percent solids for liquid sludge.

Transportation System

Transportation costs were developed using a model written for the EPA by Culp/Wesner/Culp Consultants (EPA, 1977). A detailed discussion of this model is included in Appendix B. Descriptions of system operation, equipment specifications, and cost calculation are included. For inclusion in SLUDGE, model transportation costs are updated to 1979, and sensitivity analysis was performed on variables identified in Figure 2.

Application System

Simulation of costs associated with methods, three for liquid sludge and one for dewatered sludge, is included in the SLUDGE model. These were chosen to represent methods appropriate to or previously used in forest land application which are likely to be in compliance with waste disposal regulations if carried out properly. For liquid sludge, the application methods are spray irrigation, vehicular application to the soil surface, and vehicular application with subsoil injection. For dewatered sludge, surface vehicular application is assumed. Details of these systems follow.

Four application loading rates were used in calculating application systems costs (2.5, 5.0, 7.5, and 10.0 dry tons per acre). Any other loading rate may be used in SLUDGE.

Spray Irrigation

Spray irrigation is best suited to dispersal of liquid sludges on clearcut openings or in very young forest stands. It can also be used in mature stands, as long as there is no dense understory.

The spray irrigation system consists of the use of a rotary sprayer, usually called a rain gun, to disperse liquid sludge over the application site (Figure 5). The sludge, propelled by a pump, is transferred from temporary storage to the gun via a system of pipes, which can be taken apart and reassembled when enough sludge has been applied to the area reached by the rain gun.

Short term storage can be handled by digging small temporary pits using bulldozers. No lining is needed, as sludge will not remain in the pit for more than a few days. It is assumed that one small bulldozer can dig the necessary pit in 3 hours, including travel time to the site. Bulldozers can be rented for about $45 per hour, including operator[1/]. Temporary storage can also be provided by using a portable or nurse tanker, though this option was not included in SLUDGE.

One unit of spray irrigation equipment is defined as one rain gun with stand, 600 feet of plastic or metal pipe, and one trash pump. The specifications and prices of these pieces of equipment are listed in Table 3. It is assumed that one laborer can handle two such units, and that, in use, each unit pumps for 4 hours per day with the other 4 spent in moving and setup. The rated capacities of the rain gun, in terms of gallons per minute (gpm) of water sprayed and diameter

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[1/]Personal communication, Janjer Enterprises, Lansing, Michigan.

Figure 5: Spray Irrigation Equipment

of sprayed area, are decreased by one-fourth to compensate for the fact that sludge is sprayed with a 4 percent solids content. Operation and maintenance costs for spray irrigation equipment were not available, but a pump manufacturer, ITT Marlow, indicated that maintenance costs generally mean replacement of seals and impellers and estimated that about half the original purchase price is commonly spent for this purpose throughout pump life. Accordingly, operation and maintenance costs were assumed to be half the annual purchase price of the equipment.

Table 3. Spray Irrigation Equipment: Specifications and Prices.

Item	Model	Size	Specification	Price
Rain Gun[1/]	Nelson P200R	1.29" ring nozzle	part circle spray, 27° trajectory angle, female pipe thread mount, 230 gpm, 325' diameter	$ 565.00
Pump[2/]	Homelite 160TP4-1	4"input, 4" output	16 HP engine, 36,500 gph, using 5/6 gph diesel fuel	$1,680.00
Pipe[3/]		4"	plastic or metal	$ 1.25 ft.

[1/] Source: Personal communication with Ashcraft's Irrigation Sales, Copemish, Michigan.

[2/] Sources: Personal communication with Larry's Sports Center, Wellston, Michigan and Homelite Textron, Ithaca, Illinois.

[3/] Source: Personal communication with John Cooley, USDA Forest Service, North Central Forest Experiment Station.

Spray irrigation cost is calculated as follows:

TCs = Oc + Emc

Oc = Fc + Lc

Fc = Pd + 3 1/3[1] Gc

Lc = (Pd/2[2]) * W * 8.0[3]

Pd = Sv/41,400[4]

EMc = Sc + Mc + Ec

Sc = Sc + Mc + Ec

Sc = (DTv/LR)/32[5] * 3[6] Bp

MC = (E * N/L) * .5[7]

N = Pd/250[8]

$$Ec = E * [i * (1 + i)^{L}]/[(1 + i)^{L} - 1]$$

WHERE

TCs = total cost of spray irrigation, dollars
Oc = operating cost of equipment
EMc = ownership and maintenance cost of equipment
Fc = fuel cost
Lc = labor cost
Pd = number of 4 hour pumping days needed
Sv = sludge volume
Gc = price of diesel fuel
W = wage rate, including fringes
Sc = storage cost
Mc = maintenance cost
Ec = amortized equipment ownership cost
DTv = dry sludge volume, tons
LR = loading rate, dry tons/acre
Bp = bulldozer rental rate, per hour
E = cost of one unit of spray irrigation equipment
N - number of equipment units needed
i = interest rate, %
L = life of equipment unit, years

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[1] Pump uses 3 1/3 gallons of fuel per 4-hour pumping day.

[2] Assumed one worker handles two equipment units

[3] Workday = 8 hours

4/One spray irrigation unit spreads 41,400 gallons of sludge per day.

a. Nelson P200R rain gun disperses 230 gallons of water per minute.
b. Sludge at 4 percent solids reduces capacity by 25 percent.
c. 60 minutes/hour * 4 pumping-hours/day = 240 pumping-minutes/day.
d. 230 gal./min. * .75 * 240 min./day = 41,400 gallons per day.
Specifications developed from personal communication with Ashcroft's Irrigation Sales, Copemish, MI.

5/One equipment unit can cover 32 acres per storage pit.

a. One unit has 600 ft. of pipe, reduced by 25 percent for uneven or forested ground.
b. Nelson P200R rain gun has a 325-ft. radius for water.
c. Sludge at 4 percent solids reduces capacity by 25 percent.
d. Total radius from pit = (600' * .75) + (325' * .75) = 694'.
e. Total area = πr^2 = $\pi * (694)^2$ = 32 acres.
Distances and specifications developed from personal communication with Ashcroft's Irrigation Sales, Copemish, MI.

6/Assumed one temporary storage pit can be dug in 3 hours.

7/Total maintenance cost over the life at the equipment unit is half of the equipment purchase price.

8/250 working days per year.

Surface Vehicular Application: Liquid Sludge

Liquid sludge may be spread on the soil surface from a tank-type vehicle as well as being sprayed. There are vehicles available which are designed for sludge application. These vehicles are equipped with vacuum pumps, such that they are self-loading. Sludge is stored in pits dug by bulldozers, as in the spray irrigation operation. The application vehicles load sludge directly from pits, travel to the application site, and unload the sludge as they traverse the site in order to get fairly even sludge distribution.

Liquid sludge may be spread by tanker applicators which have high flotation tires designed to minimize soil disturbance and compaction. A number of manufacturers produce such equipment. The Big Wheels, Inc. "No Trac Pac" liquid sludge applicator (pictured, Figure 6) was chosen as representative for two reasons. First, this unit has been successfully used on forest land at times with minor modifications for such use. Second, Big Wheels, Inc. provided more complete information on the specifications, operation and maintenance, and costs of the equipment than any other manufacturer contacted.

The Big Wheels "No Trac Pac" liquid sludge applicator vehicle costs approximately $53,000 to purchase, $2,000 per year for maintenance and repair, consumes an average of 6 gallons of diesel fuel per hour, and has an estimated operating life of 10 years (at 2000 hours per year). For purposes of analysis the following operating parameters are assumed: a quarter mile hauling distance from sludge source to spreading site and a 12 minute load-unload cycle. The cycle time is a conservative assumption; the optimum time is 5 to 6 minutes (Big Wheels, Inc., 1979).

Figure 6. Liquid Sludge Applicator Vehicle.

The procedures used for calculating the costs of sludge application by tanker spreading are as follows:

AC = [(WA + EC + FU * 6[1/]) * 8[2/] + (WA * 1/5[3/] + EC + FU * 6) * EX] * NS * 250[4/] + ST

or

AC = [...] * SP + ST, if less than one sludge applicator is needed.

EC = [1.1[5/] + PR * i * $(1 + i)^n/[(1 + i)^n - 1]$]/(NS * 8)

n = 20,000[6/]/[(8 + EX) * 250] if the number of applicators is greater than 1, or

n = 20,000/(8 * SP)

EX = [(SPR - NS) * 60,000[7/]/NS]/7.500[8/]

SP = SV/60,000

SPR = SP/250

ST = BP * 3[9/] * [(DV/L)/162[10/]]

WHERE

AC = total annual cost of land spreading
WA = wage rate, including fringes
EC = ownership and maintenance cost of liquid sludge applicator, per hour
FU = fuel cost per gallon
EX = hours of over time per applicator-day
NS = number of applicators, integer
ST = storage cost
SP = number of applicator-days per year
PR = purchase price of applicator
i = interest rate
n = expected equipment life, years
SPR = number of applicators, real
SV = sludge volume, gallons
BP = bulldozer rental, dollars per hour
DV = dry sludge volume, tons
L = loading rate, tons per acre

[1/] Applicator uses 6 gallons of fuel per hour.

[2/] Workday = 8 hours

[3/] Overtime wage = 1.5 times regular wage.

4/ 250 working days per year.

5/ Maintenance of applicator costs $1.10 per hour.

6/ Applicator has 20,000-hour life.

7/ Applicator spreads 60,000 gallons of sludge per average day.

8/ Applicator spreads 7,500 gallons of sludge per average hour.

9/ Assumed one temporary storage pit can be dug in 3 hours.

10/ Applicator can cover 162 acres per storage pit, calculated as follows:

a. radius from pit traveled by applicator = 400 yd.
b. applicator covers 100 yd. distance in one pass.
c. total radius from pit = 500 yd. or 1,500'.
d. total area = $\pi r^2 = \pi * (1{,}500)^2$ = 162 acres.

Distance and specifications developed from personal communication with R. Smith, Packaging Corporation of America, Manistee, MI. PCA uses the Big Wheels "No Trac Pac" applicator to spread sludge on forest land.

Subsoil Vehicular Application: Liquid Sludge

Liquid sludge can be injected into the soil using a simple attachment (pictured, Figure 7) to the standard sludge applicator vehicle described above. A three-knife subsurface applicator unit adds approximately $4,000 to the "No Trac Pac" unit; otherwise, all assumptions are the same as for liquid sludge spreading.

Injection may be a safer means of application. Sludge is buried in the soil, providing fewer routes for pathogens and pollutants to escape from the site, as well as looking cleaner and reducing odor problems. The major drawback is that, on forest lands, roots may interfere with the injection equipment, possibly to the extent that injection is infeasible on many sites. This method is only suitable where the soil and litter layer is fairly deep, with no large roots within 8 to 9" of the surface. Areas that have been root-raked and burned may be suitable, as are areas like old fields that are to be converted to plantations.

Cost calculations for subsoil injection of liquid sludge are the same as for surface vehicular application, presented in the preceeding section.

Figure 7. Subsoil Injection Applicator Vehicle.

Surface Vehicular Application: Dewatered Sludge

Surface spreading of dewatered sludge is almost exactly like surface application of liquid sludge. The vehicle (pictured, Figure 8) is somewhat different: instead of a tank, it has a bed, and instead of loading itself, it is loaded by a front-end loader. Since dewatered sludge usually behaves more like a solid than a liquid, it is not necessary to dig short term storage pits for dewatered sludge. It is simply piled up as it reaches the site, and the application vehicle and front end loader use the piles as temporary storage.

The Big Wheels Dry Sludge Unit has a 7 cubic yard material box and a chain type conveyor specifically designed to distribute sludge on land. The unit costs approximately $48,000, and the operating prices and characteristics are the same as those of the liquid sludge applicator.

The loader used is a John Deere four-wheel-drive, 1.5 cubic yard loader, costing approximately $50,000, with an estimated operating life of 10,000 hours. The manufacturer estimates $21.00 per hour total owning and operating costs for this unit, including 15 percent for depreciation, insurance, and taxes.

Dewatered sludge vehicular application costs were calculated as follows:

AC = [(LO + SP) * (WA * 8[1/] + WA * 1.5[2/] * EX) + (B + EX) * LO *
(LC + 4[3/] * FU) + SP * (SC + 6[4/] * FU)] * 250[5/]

<u>or</u>

AC = [(WA + FU * 4)/4[6/] + (WA + FU * 6)] * 8 * SP + SPC + LDC,
if only one applicator is required.

LO = SP/4

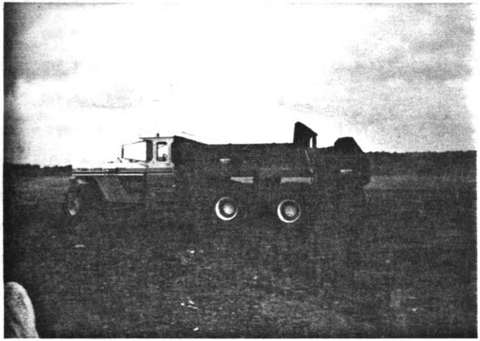

Figure 8. Dewatered Sludge Applicator Vehicle.

SP = SPR, integer

SPR = SD/250

EX = [(SPR - SP) * 288[7]/SP]/36[8]

LC = [LO * i * $(1 + i)^r$/[$(1 + i)^r$ - 1]]/[(8 + EX) * 250] +

(LO * 1.9[9]) * (LO/SP)

SC = [SP * i * $(1 + i)^n$/[$(1 + i)^n$ - 1]]/[(8 + EX) * 250] +

(SP * 1.1[10])

SPC = [SP * i * $(1 + i)^n$/[$(1 + i)^n$ - 1] + 1.1] * (8 * SD)

LDC = [LD * i * $(1 + i)^r$/[$(1 + i)^r$ -1] + 1.9] * (8 * SD)

SD = SV/288

n = 20,000 * SP/(SD * 8)

r + 10,000 * LO/[(SD * 8) * (LO/SP)]

<u>where</u>

AC = cost of dewatered sludge application
LO = number of front-end loaders, integer
SP = number of applicators, integer
WA = wage rate, dollars per hour, including fringes
EX = average overtime, hours per day, for each applicator and front-end loader
LC = annual maintenance and ownership cost of front-end loader
FU = cost of diesel fuel, dollars per gallon
SC = annual maintenance and ownership cost of applicator
SPC = annual maintenance and ownership cost of applicator when only one applicator is required
LDC = annual maintenance and ownership cost of front-end loader when only one applicator is required
SD = number of days required to apply sludge per year
SPR = number of applicators, real
i = interest rate
n = equipment life, applicator, in years
r = equipment life, front-end loader, in years
SV = sludge volume, cubic yards per year

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[1] 8 hour working day.

[2] Overtime wage premium is 1.5 times regular wage

[3] Front-end loader uses 4 gallons of fuel per hour.

[4] Applicator uses 6 gallons of fuel per hour

5/ 250 working days per year.

6/ One front-end loader required for each 4 applicators.

7/ Applicator spreads 288 cu. yd. per day.

8/ Applicator spreads 36 cu. yd. per hour.

9/ Maintenance cost for front-end loader is $1.90 per hour.

10/ Maintenance cost for applicator is $1.10 per hour.

Note: Annual costs of equipment are calculated differently when only one applicator is required, because the equipment life (in years) is longer if not used to capacity each year of operation. No equipment was amortized for more than 30 years. Equipment lives are:

Applicator: 20,000 hours
Front-end loader: 10,000 hours

Groundwater Monitoring System

Monitoring is not legally required at present on land application projects. However, in light of the attitudes of the public toward waste disposal, it would be foolish not to include monitoring in a land disposal operation, even if only at the beginning, to insure groundwater contamination is not occurring with routine operation.

There are different ways of testing subsurface waters. Wells were chosen for the SLUDGE model, so that actual groundwater testing could be done. Suction lysimeters and streamwater testing have also been used (Edmonds and Cole, 1980), but do not sample groundwater. The Environmental Protection Agency recommends that groundwater monitoring be done using wells in threes: one on-site, one up-groundwater gradient from the site, and one down-groundwater gradient from the site. On very small operations, it might be feasible to use fewer sets of wells. In any operation, the number of well sets is determined by the following:

1. The area (acreage) upon which sludge is applied;
2. The hydrologic characteristics of the area; and
3. The sludge loading rate.

The Environmental Protection Agency (1975) advocates an intense monitoring program. In addition to fairly frequent groundwater monitoring, the EPA indicates that soil and plant testing are also desirable. However, there are no standards for contaminants in plants and soil, and techniques for monitoring these systems are not standardized, making estimation of these monitoring costs difficult (EPA, 1975). EPA Plant monitoring recommendations are aimed at determining levels of cations and anions in food crops. These levels are not as critical in the forest ecosystem, where plants do not generally enter human food chains.

Since the regulations which pertain to noncropland application of sludge can be met, in general, by proper site design or selection and control of surface water runoff, only groundwater monitoring was included in this study.

Groundwater monitoring is assumed to be performed in accord with EPA recommendations (EPA, 1975). A listing of the test parameters and estimated costs of such tests appears in Table 4. A total cost of chemical analysis of all parameters of average samples is estimated at $114.50. It is assumed that a technician collecting groundwater samples can gather samples from four wells per hour. Two hours travel time is included for the technician to travel to and from the disposal site. The average technician's wage is assumed to be $17.50 per hour. Groundwater samples are taken from two-inch monitoring wells, cased in galvanized steel with the wellhead located in the 0 to 10 foot level. Base level drilling costs of $12.00 per foot are assumed.

Table 4. Groundwater Sample Monitoring Parameters and Costs.

Parameter[1/]	Cost[2/] (ppm analysis)
Chloride	$ 4.50
Specific Conductance	4.00
pH	3.50
Total Hardness	7.75
Alkalinity	6.00
Ammonia-Nitrogen	10.25
Nitrate-Nitrogen	11.25
Kjeldahl Nitrogen + Phosphorous	10.25
Total Phosphorous	8.75
COD	12.50
BOD	18.25
Heavy metals found in sludges applied (per metal)	6.50[3/]

Note: The costs listed here are for separate tests. A complete groundwater analysis costs approximately $114.50, much less than the cost of each test performed individually[2/].

[1/] Source: United States Environmental Protection Agency, J.M. Syatt, and P.E. White, Jr. Sludge Processing Transportation and Disposal Resource Recovery: A Planning Perspective. WPD 12-75-01, Water Planning Division, Washington, D.C. December, 1975.

[2/] Source: Personal communication with Serco Sanitary Engineering Laboratories, Inc., Roseville, Minnesota.

[3/] Such metals may include:

Anions - Arsenic, Boron, Chromium, Flourine, Iodine, Molybdenum, Selenium, Vanadium.

Cations - Barium, Cadmium, Cobalt, Copper, Iron, Manganese, Mercury, Lithium, Nickel, Lead, Strontium, Zinc.

NONQUANTIFIED COSTS

The costs of land application of sludge, as mentioned previously, are not restricted to expenditures for land, labor, and equipment. Public attitudes toward land application may also impose substantial costs or risks. The costs of dealing with the public and minimizing the risks of incurring liability have not been quantified in the literature, but they exist. In some cases these costs are a bigger obstacle than the actual transportation, application, and monitoring expenditures.

There is a small but vocal movement today which seeks to redefine sludge as a resource: a reserve of nutrients or metals which had not been tapped for most of our history due to a lack of economic incentives (Goldstein, 1977; McNulty, 1978). It has been shown that waste application may stimulate agricultural or silvicultural crop production (Morin, 1979; EPA, 1973; Stednick and Wooldridge, 1979; Goldstein, 1977; Edmonds and Cole, 1980). Many European and Near- and Far-Eastern cultures routinely reuse their waste on agricultural land. Americans, however, seem to have different attitudes toward human waste. By and large, America is prone to consider its municipal waste as filth, and its beneficial reuse as a "primitive agricultural practice" (Metcalf and Eddy, 1978). Hence, a potential agricultural asset remains an ecological liability.

There are two principal reasons for public aversion to the use of sludge as a resource besides the general tendency of people in America to be squeamish about much of their own biology. First, sludge smells. It doesn't necessarily smell like manure, but the odor can be strong and unpleasant, and may often be the greatest source of concern (Mosier, et. al., 1977). Second, there are pathogens in sludge: viral or bacterial vectors of some really dreadful diseases. Either or both of these factors, if not properly controlled, may cause adverse public reaction. The issues of health and nuisance, are treated at greater length in Appendix E.

Other reasons why people object to sludge include: it may be unsightly, attract flies, or leak from transportation or application equipment away from the disposal site, and it contains heavy metals, which may (if ingested) cause health problems. Heavy metals can be an issue where the public is somewhat better informed than is usually the case. Spills, bugs, and visual quality problems are usually confined to the immediate vicinity of the disposal site.

The role played by public opinion--and the cost incurred in dealing with it--is not entirely clear. Clearly, there are reasons to dislike sludge. It is not entirely clear that there are good reasons to consider properly managed sludge disposal operations on forest land objectionable. The documented history of public reactions to land application is somewhat contradictory: sometimes land application is carried out uneventfully, while other operations seem to invite disfavor.

In 1978, the author attended a conference in Orlando, Florida, entitled "The Fifth National Conference on Acceptable Sludge Disposal Techniques: Cost, Benefit, Risk, Health, and Public Acceptance." During a question-answer period following a series of presentations on the fate of organics, pathogens, and trace elements, one apparently frustrated director of a small treatment plant in New Jersey stood up and said, "Look, this is all very impressive, but I hear one question every day, and I don't know the answer, so I'm asking you. Is this stuff safe?" The treatment plant director was obviously trying to deal with public opinion, and was not quite sure how to do it.

Other municipalities report no problems. In a 1977 EPA study of landspreading cases, there is little mention of any public opinion related problems in any of the 24 municipalities studies (EPA, 1977b). From the same study, however, came two cautionary notes:

> ...farmers (in Bethlehem, Pennsylvania) were not eager to receive sludge because of a recent Pennsylvania State University study which pointed out potential problems with sewage sludge due to heavy metals.

> Liquid sludge is now used on agricultural lands. This practice has resulted in a limited number of complaints concerning odors... It is assumed that the complaints have resulted from applying liquid sludge near residences without discing the sludge under.

None of the cases in the EPA's 1977 study involved forest land application. Whether or not forest land application of sludge will stimulate much public controversy is uncertain. Some researchers have hypothesized that forestland application could be widely accepted (Sagik, Moore, and Sorber, 1979), particularly if the waste manager involves local residents in the disposal planning operation (Pratt, et. al., 1977).

However, even well-organized, candid public involvement is not necessarily guaranteed to win support for any sludge disposal scheme. Metcalf and Eddy (1978) point out that the word "sludge" itself conjures up nasty images:

> ...(one) modern commentator on the problem of sludge application notes that the word "sludge" contains "one of the worst combinations of consonants in the English language--the 'SL' sound. "...identified by the famous linguist and newspaperman, H.L. Menckhen (sic) in The American Language. Words such as slick, slimy, slither, slop, slippery, sloth, sloven, sluggish, slum, sly all have pejorative or negative meanings and sound the same.

Metcalf and Eddy also point out that the reuse of human waste has been practiced for hundreds of years in the Far East, and has acquired, as a result, the stigma associated with being a primitive agricultural practice.

Conflicting or less-than-full information from waste managers also tends to alienate the public. McNulty (1978) cites several instances when people living or near land proposed for beneficial (e.g. fertilizer) reuse of sludge became opposed to a proposed landspreading scheme because of errors and secrecy on the part of the waste management and public health agencies. Pratt, Thorne, and Wiersma (1977) agree:

> Too frequently, individuals in charge of waste utilization projects tend to alienate local residents unnecessarily. This may happen because of unguided enthusiasm for the project, or inability to recognize other viewpoints. "Benefits" of the project which are enumerated and publicized may not appear as benefits to people concerned about or affected by the problem.

In addition to problems of mismanagement, many authors point out, as Metcalf and Eddy do, that even without any impropriety the public tends to regard land application of sludge with suspicion, at best. McNulty (1978) said it best:

> Sludge seems to assume the characteristics of where it came from. If it is our sludge, agricultural use is supported; if it is their sludge, it is bitterly opposed. Large metropolitan area sludge especially is perceived as embodying all the ills of an urban society...

It is impossible to draw any hard and fast conclusion about the role of public opinion. The indications that are apparent so far are hardly suprising, but it is probably worthwhile for the sludge manager to bear them in mind. First, the "public" tends to mistrust and dislike sludge, though in general people are not very knowledgeable about sludge or its disposal. It is not expected that this "ambient" level of concern will diminish; in fact, problems associated with any method of sludge disposal are expected to increase (Brough, 1974).

Another factor which will increase the public's negative feelings toward land application, in particular, is the distance between production and disposal sites. When the sludge production area is economically, socially, and politically removed from the disposal site, local residents tend to exaggerate their fears and concerns (Montague, 1975). Mismanagement may amplify this natural skepticism to the point where any particular sludge disposal plan, no matter how cost-effective or "safe", may become infeasible.

Public interest groups, including potential users or landowners, must be included in the sludge disposal planning process, starting in the initial planning stages. If these groups are excluded, they tend

to view the disposal project as an attempt to cheat or dupe them (McNulty, 1978). Finally, the sludge disposal options must be presented with honesty and candor, even where the information may seem highly technical. Concerned citizens have the ability to grasp complicated information, for if they are truly concerned, they will take the time to learn the subject in question.

In short, land disposal is not a particularly popular activity, but it can be done, and with public support. Management must be aware that public opinion can be a powerful force, and devote the same effort to procuring public support as is given to securing the other necessary inputs to the sludge disposal operation. Although costs of public relations are not included in SLUDGE, these costs may be extremely important. Adverse public reactions, if not dealt with effectively, can effectively prevent land application operations from taking place.

SLUDGE DISPOSAL COSTS

This chapter presents the disposal costs calculated by SLUDGE. Transportation, application, and monitoring costs are presented independently. The sensitivity of each cost element to changes in key variables accompanies the discussion of base-level costs. Where documentation of costs experienced in similar operations is available, comparisons with costs calculated by SLUDGE are included.

TRANSPORTATION SYSTEM

Liquid Sludge Transportation

Base-Level Costs

Liquid sludge can be transported by trucks, railroad, barge, and pipeline. Truck transportation is considered only for one-way haul distances up to 80 miles; barge and rail are only used when the one-way transportation distance is 20 miles or more. Pipe transportation may be used for any haul distance. Tables 5 to 7 list the transportation costs for liquid sludge, using base price assumptions, and assuming no loading/unloading facilities. Truck transportation is a viable transport option when the annual sludge volume is 100 million gallons (mg) or less. Rail and barge transportation are generally economical only when volumes exceed 10 mg/year.

Several things are apparent in the transportation model. The

Table 5. Annual Costs of Transporting 50 mgd Liquid Sludge, No Facilities Included (Base Rates)1/.

Table 5. *Annual* Costs of Transporting 50 mg. Liquid Sludge, No facilities Included (Base Price)[1].

Mode of Transportation	Distance, Miles						
	5	10	20	40	80	160	320
			(total costs are in thousands of dollars)				
Truck - Total	502.50	879.20	695.90	1,205.60	2,225.00	NA	NA
Per Dry Ton	60.22	105.36	83.39	144.47	266.63		
Rail - Total	NA	NA	734.50	954.80	1,285.30	2,019.80	3,305.10
Per Dry Ton			88.02	114.41	154.02	242.04	396.06
Barge - Total	NA	NA	498.90	790.60	1,113.20	2,058.90	4,529.20
Per Dry Ton			59.79	85.03	133.40	246.72	542.75
Pipe - 6" Total[2]	69.20	138.40	276.60	553.20	1,106.60	2,213.00	4,426.20
Per Dry Ton	8.29	16.58	33.15	66.30	132.60	265.19	530.39
Pipe - 10" Total	72.70	154.40	290.90	581.70	1,163.40	2,326.80	4,653.70
Per Dry Ton	8.71	17.43	34.85	69.71	139.41	278.83	557.66
Pipe - 14" Total	84.00	168.00	336.10	672.20	1,344.40	2,688.70	5,377.50
Per Dry Ton	10.07	20.14	40.27	80.55	161.10	322.20	644.40

Table 5 (cont'd.).

Pipe - 18" Total	108.60	217.20	434.30	865.70	1,737.40	3,474.70	6,949.50
Per Dry Ton	13.01	26.02	52.05	104.10	208.19	416.39	832.77

1/ Base price assumptions:
- Price of diesel fuel = $0.90 per gallon
- Trucking labor wage (including fringes) = $10.00 per hour
- Tug billing rate = $190.00 per hour
- Pipeline pumping day = 8 hours, except where otherwise noted
- For distances of 5 to 10 miles, 2500-gallon tank truck assumed; otherwise 5500-gallon tank truck assumed.

2/ 12-hour pumping day used.

Table 6. Annual Costs of Transporting 250 mg. Liquid Sludge, No Facilities Included (Base Price).

Mode of Transportation	Distance, Miles						
	5	10	20	40	80	160	320
			(total costs are in thousands of dollars)				
Truck - Total	NA	NA	NA	NA	NA	NA	NA
Per Dry Ton							
Rail - Total	NA	NA	3,856.00	4,896.50	6,181.80	9,793.00	18,361.90
Per Dry Ton			92.41	117.35	148.16	234.70	440.07
Barge - Total	NA	NA	1,832.60	3,189.30	5,209.90	10,392.10	20,146.10
Per Dry Ton			43.92	76.44	124.86	249.06	482.83
Pipe 10" Total [1/]	80.50	160.90	321.90	643.70	1,287.50	2,575.00	5,150.10
Per Dry Ton	1.93	3.86	7.71	15.43	30.85	61.72	123.43
Pipe 14" Total [2/]	87.90	175.80	351.60	703.20	1,406.50	2,812.80	5,625.80
Per Dry Ton	2.10	4.22	8.42	16.85	33.71	67.41	134.83
Pipe 18" Total	180.60	217.20	434.30	868.70	1,737.40	3,474.70	6,949.50
Per Dry Ton	2.60	5.20	10.41	20.82	41.64	83.28	166.55

Table 6 (cont'd.).

[1]/Assumes 20-hour pumping day.

[2]/Assumes 12-hour pumping day.

Note: Truck haul not considered for sludge volumes > 150 mg./year. 6" pipe cannot transport > 134 mg/year.

Table 7. Annual Costs of Transporting 500 mg. Liquid Sludge, No Facilities Included (Base Price).

Mode of Transportation	Distance, Miles						
	5	10	20	40	80	160	320
	(Total costs are in thousands of dollars)						
Truck - Total	NA	NA	NA	NA	NA	NA	NA
Per Dry Ton							
Rail - Total	NA	NA	7,888.10	9,854.20	12,302.50	20,810.20	33,663.50
Per Dry Ton			94.52	118.09	147.42	249.37	403.40
Barge Total	NA	NA	3,499.70	6,288.90	10,330.70	39,667.20	
Per Dry Ton			41.94	75.36	123.80	249.35	475.34
Pipe 14" Total[1/]	92.70	185.40	371.00	742.00	1,484.00	2,967.90	5,936.00
Per Dry Ton	1.11	2.22	4.45	8.89	17.78	35.57	71.13
Pipe 18" Total[2/]	111.80	223.70	447.20	894.50	1,789.10	3,578.10	7,156.30
Per Dry Ton	1.34	2.68	5.35	10.72	21.44	42.88	85.76

[1/] Assumes a 20-hour pumping day.

[2/] Assumes a 12-hour pumping day.

haul distance has a significant effect on transportation cost no matter what mode is chosen. Truck and rail haul costs increase, but do not quite double, as the haul distance doubles. The same is true of barging costs[1/] up to a one-way haul distance of 160 miles. Pipeline transport, on the other hand, is a straight-line function of distance. That is, for a given sludge volume, pipeline transport cost doubles as the distance doubles.

When sludge volume is 50 mg. per year, pipeline transport is the cheapest alternative up to a one-way distance of 40 miles, beyond which point barge transport is the least expensive method. Barging costs, however, increase more rapidly with increasing distance than do the costs of rail, so at great distances (320 miles, here) rail becomes the least expensive mode of transportation. Truck transport is not the most cost effective method for any distance when sludge volume is 50 mg. per year, but at middle distances (20 to 40 miles) truck haul is fairly competitive with rail haul.

Large sludge volumes, 250-500 mg. per year, are always less expensive to move by pipe than by any other method. Rail and barge transport costs, while much greater than pipe transport costs, are fairly competitive with each other, with barge haul having a small

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[1/] SLUDGE estimates of barging costs are much higher than was actually experienced in one case study involving barging of sludge by the city of Chicago. This study does not break down cost calculations, however, so that the discrepancy cannot be explained. Since the transportation model used in SLUDGE was based on empirical evidence, it can only be assumed that the costs reported by the city of Chicago were calculated differently. This is unfortunate, as the Chicago case is one of the only ones using barges to transport sludge between two ports (i.e., other than for ocean dumping), making barging costs difficult to validate.

cost advantage up to 160 miles and rail being slightly less expensive at greater distances.

In cases where loading and unloading facilities must be constructed as a part of the transportation system, costs of rail, barge and truck transport are greater. Pipe transport costs remain the same. Tables 8 to 10 summarize the transport costs of liquid sludge with loading and unloading facilities included. Adding facilities to the transportation system does not substantially alter the relationships between costs.

At sludge volumes of 50 mg. per year or more, rail and barge transport are still comparable over long haul distances (greater than 160 miles), and barging is less expensive over shorter distances. When the sludge volume is 50 mg. per year and the one-way haul distance is 160 miles or more, rail and barge are both less expensive than pipeline transport. Pipeline transport is always cheaper at shorter distances if the smallest feasible pipe size is assumed.[1/]

Sludge volumes of 250 to 500 mg. per year can always be moved by pipe more cheaply than by any other mode of transportation, over all distances.

The addition of facilities has very little effect on the costs of hauling large volumes of liquid sludge, adding on the average, only a few dollars per dry ton to rail and barge transportation cost. The effect of including facilities is greater when sludge volume is smaller. Since railroad facilities are more capital intensive than

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[1/] Costs of transporting sludge using larger sized pipelines are included because a municipality may wish to install larger pipe than presently needed in order to accomodate the greater flows in the future.

barge or truck loading and unloading facilities, addition of these facilities elevates rail transport costs more than barge or truck haul costs.

Pipe, barge, and rail haul allow little flexibility in changing the destination of the sludge, so it is unlikely that any of these methods would be used alone. A complete sludge disposal system employing pipe, rail, or barge transportation would probably also use trucks to distribute sludge from the unloading points of the other systems to the field for application. If more than one form of transportation system is to be used, the model may be run again for each mode, and the results added, to calculate total transport costs.

Table 8. Annual Costs of Transporting 50 mg. Liquid Sludge, Facilities Included (Base Price).

Mode of Transportation	Distance, Miles						
	5	10	20	40	80	160	320
	(total costs are in thousands of dollars)						
Truck - Total	563.70	903.60	757.10	1,266.20	2,286.20	NA	NA
Per Dry Ton	67.55	108.28	90.27	151.80	273.96		
Rail - Total	NA	NA	856.90	1,052.80	1,469.00	2,203.04	3,672.40
Per Dry Ton			102.68	126.16	176.03	264.04	440.07
Barge - Total	NA	NA	597.20	868.70	1,351.10	2,321.30	4,308.00
Per Dry Ton			71.57	104.10	161.91	278.17	526.90
Pipe 6" - Total[1/]	69.20	138.40	276.60	553.20	1,106.60	2,213.00	4,426.20
Per Dry Ton	8.29	16.58	33.15	66.30	132.60	265.19	530.39
Pipe 10" - Total	72.70	145.40	290.90	581.70	1,163.40	2,326.80	4,653.70
Per Dry Ton	8.71	17.43	34.85	69.71	139.41	278.83	557.66
Pipe 14" - Total	84.00	168.00	336.10	672.20	1,344.40	2,688.70	5,377.50
Per Dry Ton	10.07	20.14	40.27	80.55	161.10	322.20	644.40

Table 8 (cont'd.).

Pipe 18" - Total	108.60	217.20	434.30	868.70	1,737.40	3,474.70	6,949.50
Per Dry Ton	13.01	26.02	52.05	104.10	208.19	416.39	832.77

[1]/Assumes 12-hour pumping day.

Table 9. Annual Costs of Transporting 250 mg. Liquid Sludge Facilities Included (Base Price).

Mode of Transportation	Distance, Miles						
	5	10	20	40	80	160	320
	(total costs are in thousands of dollars)						
Truck - Total	NA	NA	4,284.40	5,263.80	6,732.70	9,854.20	18,974.00
Per Dry Ton	-	-	102.68	126.15	161.36	236.17	454.74
Barge - Total	NA	NA	2,064.90	3,235.30	5,539.00	10,953.70	20,132.60
Per Dry Ton	-	-	49.49	77.54	132.75	262.52	482.51
Pipe 10" - Total 1/	80.50	160.90	321.90	643.70	1,287.50	2,575.00	5,150.10
Per Dry Ton	1.93	3.86	7.71	15.43	30.85	61.72	123.43
Pipe 14" - Total 2/	87.90	175.80	351.60	703.20	1,406.50	2,812.80	5,625.80
Per Dry Ton	2.10	4.22	8.42	16.85	33.71	67.41	134.83
Pipe 18" - Total	108.60	217.20	434.30	868.70	1,737.40	3,474.70	6,949.50
Per Dry Ton	2.60	5.20	10.41	20.82	41.64	83.28	166.55

1/ Assumes 20-hour pumping day.

2/ Assumes 12-hour pumping day.

NOTE: Truck haul not considered for sludge volumes > 150 mg. per year. 6" pipe cannot transport > 124 mg. per year.

Table 10. Annual Costs of Transporting 500 mg. Liquid Sludge, Facilities Included (Base Price).

Mode of Transportation	Distance, Miles 5	10	20	40	80	160	320
			(total costs are in thousands of dollars)				
Rail - Total	NA	NA	8,507.70	10,405.10	13,465.40	19,892.10	36,111.80
Per Dry Ton	-	-	101.95	124.69	161.35	238.37	432.74
Barge - Total	NA	NA	3,899.40	6,193.60	10,773.80	21,744.10	39,802.10
Per Dry Ton	-	-	46.73	74.22	129.11	260.56	476.96
Pipe 14" - Total[1/]	92.70	185.40	371.00	742.00	1,484.00	2,967.90	5,936.00
Per Dry Ton	1.11	2.22	4.45	8.89	17.78	35.57	71.13
Pipe 18" - Total[2/]	111.80	223.70	447.20	894.50	1,789.10	3,578.10	7,156.30
Per Dry Ton	1.34	2.68	5.35	10.72	21.44	42.88	85.76

[1/] Assumes 20-hour pumping day.

[2/] Assumes 12-hour pumping day.

Dewatered Sludge Transportation

Base-Level Costs

Only two modes of transportation are useful for moving dewatered sludge: truck and rail (tables 11 and 12). Barges have not been widely used for dewatered sludge transportation due to unloading difficulties.

Rail transport is cheaper than truck transport for all annual sludge volumes and distances studies, both with and without loading and unloading facilities.

It is much less expensive to transport dewatered sludge, by either rail or truck, than liquid sludge because the volume of dewatered sludge is much less than that of liquid sludge per dry ton of solids.[1/] The Rutgers study (Kasper, et. al., 1973) reached the same conclusions.

There are substantial economies of scale in both truck and rail transportation of dewatered sludge, with facilities. Without facilities, only truck transportation shows economies of scale on a per-dry-ton basis. Transport costs on this basis decrease when sludge volume is increased, with the cost decreases being more dramatic at lower hauling distances.

As distance increases, both truck and rail transportation costs increase at an increasing rate.

Loading and unloading facilities add much more to transport costs at low volumes and distances than at high volumes and distances, adding

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[1/] This does not mean that sludge should be dewatered for the purpose of land application. Dewatering is also a costly operation, and the cost of reducing sludge volume must be weighed against the difference in transport costs. Costs of dewatering are not a part of this model, but they may be found in other sources (Bauer, 1973; EPA, 1975; Kasper, et. al., 1973).

Table 11. Costs of Transporting Dewatered Sludge: No facilities Included (Base Price).

Sludge Volume 1000 cu. yd./yr.	Mode of Transportation	Distance, Miles 5	10	20	40	80	160	320
		(total costs in thousands of dollars)						
5	Truck-Total	14.90	18.70	20.00	28.90	46.80	NA	NA
	Per Dry Ton	16.05	20.15	21.55	31.14	50.42	-	-
50	Truck-Total	48.70	77.20	138.80	203.70	419.20	NA	NA
	Per Dry Ton	5.25	8.32	14.95	21.95	45.17	-	-
	Rail-Total	NA	NA	95.50	134.70	202.00	229.90	550.90
	Per Dry Ton	-	-	10.29	14.51	21.76	32.31	59.36
250	Rail-Total	NA	NA	489.70	661.00	1,003.80	1,530.20	2,754.30
	Per Dry Ton	-	-	10.55	14.24	21.63	32.97	59.35
500	Rail-Total	NA	NA	979.30	1,285.30	2,050.40	2,937.90	5,386.20
	Per Dry Ton	-	-	10.55	13.85	22.09	13.65	58.03

Table 12. Costs of Transporting Dewatered Sludge: Facilities Included (Base Price).

Sludge Volume 1000 cu. yd./yr.	Mode of Transportation	Distance, Miles 5	10	20	40	80	160	320
		(total costs in thousands of dollars)						
5	Truck-Total	39.40	45.70	49.40	58.30	72.50	NA	NA
	Per Dry Ton	42.45	49.24	53.23	62.81	78.11	-	-
50	Truck-Total	100.10	144.50	193.90	258.80	431.40	NA	NA
	Per Dry Ton	10.78	15.57	20.89	27.88	46.48	-	-
	Rail-Total	NA	NA	171.40	226.50	269.30	379.50	648.80
	Per Dry Ton	-	-	18.49	24.40	29.01	40.89	69.90
250	Rail-Total	NA	NA	599.80	765.10	1,040.50	1,530.20	2,815.50
	Per Dry Ton	-	-	12.92	16.49	22.42	32.79	60.67
500	Rail-Total	NA	NA	1,040.50	1,377.10	2,050.40	2,937.90	5,508.60
	Per Dry Ton	-	-	11.21	14.84	22.09	31.65	59.35

almost nothing to costs of transporting 250 or more cubic yards per year 160 to 320 miles.

As noted in the previous section dealing with liquid sludge transportation, railroads are less flexible than trucks with respect to the route or destination. If rail haul is used, it is quite likely that trucks will also be required to transport sludge from the rail sidings where it is unloaded to the application site.

Sensitivity Analysis

The transportation model used to develop cost estimates in SLUDGE is an adaptation of an earlier model (hereinafter referred to as the CWC model), as noted previously. To the extent possible, individual variables affecting transportation costs were isolated, and their effect on the total sludge transportation cost tested. The preceeding sections have shown the effects of the two most important variables, sludge volume and transportation distance, on transportation costs. The effects of other variables may be of interest as well.

One cost element that has attracted a great deal of attention recently is fuel. Costs of fuel have risen nearly 75 percent faster than costs of other wholesale goods since 1973. This concerns sludge managers, for many of the required waste treatments require great quantities of fuel. Some disposal options require more fuel than others. The almost universally cited example of a fuel-intensive disposal option is incineration (thermal disposal). This option requires that the sludge be dewatered to 25 to 30 percent solids before incineration by centrifugation or vacuum filtration, at which point it will sustain combustion in multiple hearth furnaces. In lieu of dewatering to 25 to 30 percent solids, sludge may be incinerated with additional fuel being added constantly to maintain combustion and prevent corrosion of the furnaces. Either way, the annual fuel consumption of incineration is usually high compared to fuel used in land application systems (Metcalf and Eddy, 1978).

Transportation is generally considered one of the most fuel-intensive elements of a land application system, particularly when trucks are used to transport the sludge. Table 13 shows the effect of increasing the cost of diesel fuel on the cost of truck transport. It is apparent from this table that the effect of increases in fuel prices is fairly minor, compared to the effects of other factors such as transportation distance and sludge volumes. Even when the price of fuel rises by one-third, the total trucking cost rises by no more than 6 percent (Table 13).

Another factor which affects trucking costs is the wage paid to truck drivers. Table 14 shows that the magnitude of the effect caused by changes in wage rates is smaller as truck size increases. This is logical, considering that smaller trucks must make more trips, increasing the variable/fixed cost ratio. The effect of wage changes is smaller as transportation distance increases. Wage rate is a larger component of truck transportation cost than is fuel cost, as evidenced by the fact that the effect of raising the wage rate is much greater than that of changing the cost of diesel fuel.

Both wages and fuel prices are factors in barging costs. Changes in these costs are not usually borne directly, however. The tug billing rate incorporates changes in wages, fuel prices, and such things as equipment cost and amortization associated with operating the boats. The base billing rate is $190.00 per hour, assuming 2,000 horsepower tugboats and 500,000 gallon barges. Table 15 summarizes the effect of changing the tug billing rate on the cost of barge transportation of liquid sludge. These effects are almost constant, varying little with sludge volume and transportation distance. In general, raising the tug billing rate by almost one third raises barge transportation costs by approximately one fourth to one third.

Table 13. Percentage Increase in Trucking Cost With 33 1/3 percent Increase in Fuel Cost.

Sludge Volume	Distance, Miles				
	5	10	20	40	80
50 mg. per year	2.8%	3.0%	4.5%	5.0%	5.6%
10,000 cu. yd. per yr.	4.4%	5.6%	4.3%	5.5%	5.4%

Table 14. The Effect of Changes in Trucking Labor Wage Rate on Sludge Transportation Cost.[1/]

Annual Sludge Volume	Change in Wage Rate (percent)	Distance, Miles				
		5	10	20	40	80
		(cost per dry ton of sludge)				
50 mg./yr.	50%	26.9%	19.2%	16.8%	13.9%	13.0%
5,000 cu. yd./yr.	50%	13.5%	16.4%	10.1%	10.7%	11.8%
50,000 cu. yd./yr.	50%	42.0%	36.4%	15.9%	15.5%	12.6%

[1/] No facilities included.

Table 15. The Effect on Barge Transportation Cost of Changes in Tug Billing Rate, Liquid Sludge.

Sludge	Change in Billing Rate (percent)	Transportation Distance, Miles 20	40	80	160	320
		(cost per dry ton of sludge)				
50 mg./yr.	32%	20.8%	24.3%	27.9%	28.5%	25.2%
250 mg./yr.	32%	28.3%	27.1%	29.8%	28.2%	28.3%
500 mg./yr.	32%	26.5%	27.8%	38.8%	32.0%	26.8%

Other than transportation distance and sludge volume, no elements were varied in rail and pipeline transport. This is due in part to the way rail and pipeline costs are calculated in the CWC model[1/] and in part to the fact that rail and pipeline costs are primarily affected by site specific factors which are difficult to simulate.[2/]

The variable which has the greatest effect on the cost of transporting both liquid and dewatered sludge is transportation distance. The effect of distance varies for different modes of transportation.

[1/]For example, rail rates, mileage credits for shipper supplied cars, and tank car lease rates are not presented individually, due to the fact that railroad companies were unwilling to supply itemized costs for quotation.

[2/]Pipeline transportation costs, for example, are heavily dependent on the number of pumping stations required. This, in turn, is a function of how many major and minor roads cross the pipe route and the terrain on which the pipeline is built. Certain assumptions regarding these factors are made in order to calculate pipeline transportation costs in the CWC model, but no attempt is made to represent actual conditions in any particular area, as individual conditions are highly variable. Similarly, rail transportation costs are dramatically affected by shipping time. Rail haul costs presented in one study (Sheaffer and Roland, Inc., 1978) are less than half the cost predicted by SLUDGE due mostly to a striking difference in transit time. SLUDGE uses rail transit time figures provided by a commercial railroad (Southern Pacific), which averaged several days for even short journeys of 20 miles or so. The Lake County study, on the other hand assumes a one-way travel time of approximately ten hours of 220 miles, a difference of over 150 hours. This large difference is explained by the differences in ownership and control assumed in the two studies. SLUDGE assumed that the shipper rents cars and accepts standard rail route scheduling. The Lake County study, in contrast, has the shipper buying the cars, locomotives, and tracks, eliminating most of the delays and all other shippers over the route. It is clear, then that rail transport costs can be cut if the sludge producer owns his own railroad. This may be practical for situations such as that described in the Lake County study, where six large treatment plants (Detroit, Wayne County, Warren, Pontiac, Flint, and Saginaw) are all utilizing the same transport-disposal system, and a railroad, which is already in place, is available.

Pipeline transportation costs generally exhibit the greatest distance effect, doubling as the distance doubles. The effect of transportation distance on other forms of transportation is more complicated. Barging costs increase by approximately 40 to 80 percent for 50 to 500 mg. of liquid sludge, respectively, as the distance doubles (from 20 to 40 miles, one way). Increasing the barging distance from 160 to 320 miles, causes the total transportation cost to nearly double.

Rail transport costs are not as greatly affected by distance as are barging costs, but the relative effects are similar. That is, doubling distance from 20 to 40 miles does not affect the total cost as much as doubling the one-way haul from 160 to 320 miles. The increase in transportation cost attributable to doubling the rail transportation distance varies from approximately 30 to just over 60 percent, depending on the original distance.

Trucking costs are also greatly dependent on transportation distance. The effect of distance on total trucking costs is, in general, greater when the sludge is liquid than when dewatered sludge is used; increases in trucking cost from doubling distances vary from 66 percent to 85 percent for liquid sludge, and from 27 to 106 percent for dewatered. The 106 percent rise occurs only when doubling the distance from 40 to 80 miles for 50,000 cubic yards per year; otherwise, the greatest effect on costs is approximately 62 percent. The distance effect is greater, in general, when no loading and unloading facility costs are included in the total cost.

There may be substantial economies (on a per-dry-ton basis) associated with transporting larger liquid sludge volumes, particularly with pipeline transport. Pipeline costs depend on sludge volume only to the extent that greater volumes may require larger pipes or longer pumping days. By far the most important single variable affecting pipe transport costs is transportation distance. The per-dry-ton pipeline transport costs go down markedly as sludge volume increases, even assuming that larger pipe and longer days are required.

When no facilities are included, barge transportation costs per dry ton of sludge also tend to decrease as liquid sludge volume increases, although not so dramatically as pipeline transport costs.

Trucking costs per dry ton remain about the same as liquid sludge volume changes, while rail transportation costs increase by small amounts as volumes increase. Table 16 is a summary of the effects of sludge volume on liquid sludge transport costs, per dry ton (without including facilities).

When loading and unloading facilities are included, the picture changes somewhat. Rail and barge costs tend to decrease slightly as sludge volume increases, though the effect is much less in both systems than in truck transportation (Table 17). Pipeline costs, of course, do not change.

Dewatered sludge rail transportation costs also exhibit some economies associated with increasing sludge volume, as shown in Table 18.

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Table 16. The Effect of Liquid Sludge Volume on the Costs (Per Dry Ton) of Transportation, No Facilities.

Mode of Transport	Distance, Miles	Sludge Volume 50 mg.	250 mg.	500 mg.
		(cost per dry ton of sludge)		
Rail	20	88.02	92.41	94.52
	40	114.42	117.35	118.09
	80	154.02	148.16	147.42
	160	242.04	234.70	249.37
	320	396.06	440.07	403.40
Barge	20	57.38	47.28	41.24
	40	79.50	76.84	75.09
	80	123.73	124.23	125.19
	160	235.67	239.54	250.32
	320	515.28	473.10	456.59
Pipe	5	8.29 1/	1.93 2/	1.11 3/
	10	16.58	3.86	2.22
	20	33.15	7.71	4.45
	40	66.30	15.43	8.89
	80	132.60	30.85	17.78
	160	265.19	61.72	35.57
	320	530.39	123.43	71.13

1/ Six inch pipe, 12 hr. day.

2/ Ten inch pipe, 20 hr. day.

3/ Fourteen inch pipe, 2o hr. day.

Table 17. The Effect of Liquid Sludge Volume on the Costs (Per Dry Ton) of Transportation, Facilities Included.

Mode of Transport	Distance, Miles	Sludge Volume 50 mg.	250 mg.	500 mg.
		(cost per dry ton of sludge)		
Rail	20	102.68	102.68	101.95
	40	126.16	126.15	124.69
	80	176.03	161.36	161.35
	160	264.04	236.17	238.37
	320	440.07	454.74	432.74
Barge	20	70.58	47.28	44.17
	40	103.02	73.91	72.16
	80	145.73	133.03	131.06
	160	257.66	248.34	250.32
	320	478.60	487.77	456.59

Tab

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Table 18. The Effect of Dewatered Sludge Volume on the Costs (Per Dry Ton) of Rail Transportation.

Distance, Miles	Facilities Available	Sludge Volume 50,000 cu.yd.	250,000 cu.yd.	500,000 cu.yd.
20	no	10.29	10.55	10.55
	yes	18.47	12.92	11.21
40	no	14.51	14.24	13.85
	yes	24.40	16.49	14.84
80	no	21.76	21.63	22.09
	yes	29.01	22.42	22.09
160	no	32.31	32.97	31.65
	yes	40.89	32.97	31.65
320	no	59.36	59.35	58.03
	yes	69.60	60.67	59.35

LAND APPLICATION SYSTEM

Spray Irrigation

Base-Level Costs

Spray irrigation has been shown to be an effective method for applying liquid sludge to forest land. Its cost is reasonable, as Table 19 shows.

Perhaps the most striking feature pertaining to these application costs (on a dry ton basis) is the insensitivity to sludge volume. This may, however, be misleading. Constant equipment and service costs are assumed. In reality, substantial economies may be achievable from discounts on buying equipment and services (such as storage pit construction) in larger lots.

There may also be substantial drawbacks involved in applying large amounts of sludge, principally related to public attitudes and health hazards. These are discussed more fully in Chapter 3 in the section dealing with non quantifiable costs, and in Appendix E.

Table 19. Costs of Spray Irrigation of Liquid Sludge (Base Level)[1/]

Sludge Volume, mg.		Loading Rate, Dry Tons/Acre 2.5	5.0	7.5	10.0
		(total costs in thousands of dollars)			
50	total	71.30	64.20	61.80	60.70
	P.D.T.	8.54	7.70	7.41	7.28
250	total	355.90	320.60	308.09	303.10
	P.D.T.	8.53	7.68	7.40	7.26
500	total	710.70	640.30	616.80	605.00
	P.D.T.	8.52	7.67	7.39	7.25

[1/]Base price assumptions include the following:
Bulldozer rental @ $45.00 per hour, with operator
Price of spray gun and mount = $565.00
Price of pump = $1,680.00
Price of pipe = $1.25 per ft.
Equipment life = 5
Price of diesel fuel = $0.90 per gallon
Application labor wage = $10.00 per hour (fringes included)
Equipment amortized at 7 percent

[2/]Per dry ton.

Sensitivity Analysis

The variation in spray irrigation application costs to changes in loading rate is not particularly great. This is due to the fact that, as the rate increases, fewer storage pits are required. This is obviously due to the way the model is constructed. In the spray irrigation operation, for instance, higher loading rates would require fewer movements of pump, pipe and gun, reducing the set-up time somewhat from the assumed 4 hours per day. By the same token, however, the sprinkler would have to run longer at each set-up in order to apply a heavier load of sludge. The net effect of increasing the loading rate on the amount of time required to apply all the sludge is, accordingly, indeterminate. If higher loading rates decrease the total time required to apply sludge, application cost will decrease with increasing loading rates, and vice versa.

Spray irrigation costs are not very sensitive to fuel price. A rise of 33 percent in the cost of diesel fuel raises the cost of application by spray irrigation by only one or two percent of all loading rates and sludge volumes. This is to be expected, considering the fact that one irrigation unit (specifically, one trash pump) uses less than one gallon of fuel per hour.

The cost of labor used in land application may also be a factor in choosing the application method. Only direct labor costs are included in the simulations. Managerial and supervisory wages are left out. Municipalities which have reported administrative costs of hauling landspreading sludge (EPA, 1977b) generally combine administration costs for transportation application. Where additional administration and supervisory capacity is needed to coordinate application, this cost must be added to application costs calculated in SLUDGE.

Even without including supervision and administration, the effect of wage rates on sludge application can be important. As Table 20 shows, increasing wage rates by 50 percent increases spray irrigation application costs by 30 to 40 percent. It is, of course, unlikely that wages would increase by 50 percent at once, but it is clear that spray irrigation is fairly labor-intensive. The SLUDGE model assumes that one worker can handle two spray irrigation units. If this labor/equipment ratio can be changed, the effect of wage rates on spray irrigation cost will also change.

The effect of equipment price changes is shown in Table 21. Spray irrigation costs are most sensitive to changes in pump price, as the pump is the most expensive component of the spray irrigation unit. However, spray irrigation costs are generally insensitive to changes in equipment prices; a rise of 108 percent in the pump price, for example, increases spray irrigation cost by less than ten percent, and the effects of pipe and rain gun price changes are even smaller.

Since it is difficult to get estimates of the life of an irrigation unit, spray irrigation costs were simulated with different unit lifetimes. The effect of changing the years of useful life of the spray irrigation unit on the costs of liquid sludge disposal are negligible. On the average, doubling the useful life of the spray irrigation unit results in a 5 percent cost savings annually, per dry ton of sludge applied.

Since the equipment cost and life are of small importance in spray irrigation, it follows that the interest rate applied to equipment purchase does not have a great effect on the cost of spray irrigation.

Table 20. The Effect of Changing Wage Rate on the Cost of Spray Irrigation Application.

Loading Rate, dry tons per acre	Wage Rate, dollars per hour	Annual Sludge Volume, mg. 50	250	500
		(costs per dry ton of sludge applied)		
2.5	10	8.54	8.53	8.52
	15	11.43	11.42	11.41
5.0	10	7.70	7.68	7.67
	15	10.59	10.58	10.57
7.5	10	7.41	7.40	7.39
	15	10.30	10.30	10.29
10.0	10	7.28	7.26	7.25
	15	10.17	10.16	10.14

[1/]Wage includes fringes, by assumption.

Table 21. The Effect of Changing Equipment Price on the Cost of Spray Irrigation Application.

Component	Price	Loading Rate	Annual Sludge Volume, mg. 50	250	500
	(dollars)	(dry tons per acre)	(cost per dry ton of sludge applied)		
Base Unit[1/]	$2246.25	2.5	8.54	8.53	8.52
		5.0	7.70	7.68	7.67
		7.5	7.41	7.40	7.39
		10.0	7.28	7.26	7.25
Pump	3,500.00	2.5	8.91	8.90	8.88
		5.0	8.07	8.06	8.04
		7.5	7.78	7.78	7.76
		10.0	7.65	7.64	7.62
Pipe, per foot	2.50	2.5	8.63	8.62	8.61
		5.0	7.79	7.79	7.76
		7.5	7.50	7.50	7.48
		10.0	7.37	7.37	7.34

Table 21 (cont'd.).

Rain Gun	1000.00	2.5	8.63	8.62	8.60
		5.0	7.79	7.77	7.76
		7.5	7.50	7.49	7.48
		10.0	7.37	7.36	7.34

[1/] Base unit consists of pipe, 600 feet, at $1.25 per foot, a rain gun at $565.00, and a pump at $1,680.00.

When the interest rate more than doubles (from 7 percent to 15 percent), the added application cost is only $0.10 per dry ton of sludge.

Surface Vehicular Application

Base-Level Costs

Surface vehicular application of sludge costs approximately twice what spray irrigation costs (Table 22). The vehicular operation is not, however, unreasonably expensive, particularly compared to most transportation costs, and it may be less upsetting to local residents. Vehicular application avoids using high pressure nozzles, sending sludge shooting through the air. This reduces the spread of aerosols, decreasing the spread of odors and potential dispersal of pathogens. Where there are nearby residents, or the operation is visible from a fairly busy road, vehicular application may be preferable aesthetically.

Like spray irrigation, surface vehicular application costs are not particularly sensitive to variations in sludge volume or loading rate, and for basically the same reasons.

Table 22. Costs of Surface Vehicular Application of Liquid Sludge (Base Level)[1/].

Sludge Volume		Loading Rate, Dry Tons/Acre 2.5	5.0	7.5	10.0
(mg./year)		(total costs in thousands of dollars)			
50	Total	$ 140.80	$ 139.40	$ 138.90	$ 138.70
	PDT[2/]	16.87	16.71	16.64	16.62
250	Total	695.90	688.90	686.60	685.40
	PDT	16.68	16.51	16.46	16.43
500	Total	1,383.90	1,370.00	1,365.30	1,363.00
	PDT	16.58	16.42	16.36	16.33

[1/]Base price assumptions include the following:
Bulldozer rental @ $45.00 per hour
Price of applicator = $53,400.00
Price of diesel fuel = $0.90 per gallon
Wage rate = $10.00 per hour (fringes included)
Equipment amortized at 7 percent

[2/]Per Dry ton.

Senstivity Analysis

All application methods rely to some extent on diesel fuel. All vehicular applicators, for both liquid and dewatered sludge, use diesel fuel, as does the pump used in spray irrigation. The application vehicles use an average of 12 gallons per hour at stress loads and 6 gallons per hour when nursing and idling. Big Wheels, Inc. estimates that an average of one-quarter of the total application time is spent at stress loads.

Raising the price of fuel 33 percent has the effect of increasing the cost of applying liquid sludges approximately 10 percent (Table 23). This is true for both surface application and subsoil injection. Fuel costs can make up almost half the hourly costs of the applicator, assuming straight-line depreciation of equipment and a fuel price of one dollar per gallon. When interest on the equipment cost is added in, fuel cost is somewhat less than half the hourly cost of ownership and operation.

Vehicular sludge applicators cost around $50,000 to $100,000 at present, and represent a much higher capital investment than a spray irrigation unit costing less than $2,250. One spray irrigation unit can disperse 41,400 gallons of sludge per day, while a liquid sludge applicator puts out 60,000 gallons in an 8-hour day, so nearly 1.5 spray irrigation units are required to deal with as much sludge as one application. Even so, the applicator cost far outweighs the equipment cost of an equivalent spray irrigation system. Hence, vehicular application costs (both surface application and subsoil injection) are more sensitive to equipment cost changes than is spray irrigation cost. Table 24 illustrates the effect of changing equipment price.

Table 23. **The Effect of Changing Fuel Price on the Cost of Surface Vehicular Application of Liquid Sludge.**

Loading Rate	Fuel Price	Annual Sludge Volume, mg.		
		50	250	500
(dry tons/acre)	(dollars/gal.)	(costs per dry ton of sludge applied)		
2.5	$0.90	$16.87	$16.68	$16.58
	1.20	18.58	18.40	18.31
5.0	0.90	16.71	16.51	16.42
	1.20	18.42	18.23	18.14
7.5	0.90	16.64	16.46	16.36
	1.20	18.35	18.17	18.08
10.0	0.90	16.62	16.43	16.33
	1.20	18.34	18.14	18.05

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While surface vehicular application costs are more sensitive to equipment price changes than spray irrigation costs, it must be noted that equipment price is still not a major factor. The wage rate can be more important (Table 25). On the average, a 50 percent increase in wages results in a 25 percent increase in application cost.

The vehicular sludge applicators have a useful life of 20,000 hours, according to the manufacturer, Big Wheels, Inc. This is a reliable estimate, according to one user of the equipment, and, therefore, no sensitivity tests were performed on this variable.

Very often, the equipment used to apply sludge to land represents a sizable investment, particularly to small municipalities. Therefore, the interest rate applicable on this investment may be of considerable concern. Table 26 illustrates the effects of changing interest rates on the annual costs of surface vehicular application. As the equipment cost does not vary with changes in loading rates, the additional costs shown are applicable to all loading rates.

Table 24. The Effect of Changing Equipment Price on Surface Vehicular Application of Liquid Sludge.

Equipment Price	Loading Rate	Annual Sludge Volume, mg.		
		50	250	500
(dollars)	(dry tons/acre)	(costs per dry ton of sludge applied)		
$53,400.00	$2.5	$16.87	$16.68	$16.58
	5.0	16.71	16.51	16.42
	7.5	16.64	16.46	16.36
	10.0	16.62	16.43	16.33
75,000.00	2.5	18.06	17.89	17.81
	5.0	17.90	17.72	17.64
	7.5	17.83	17.67	17.59
	10.0	17.82	17.64	17.56

Table 25. The Effect of Changing Wage Rate on the Cost of Surface Vehicular Application of Liquid Sludge[1].

Loading Rate	Wage Rate[2]	Annual Sludge Volume, mg.		
		50	250	500
(dry tons/acre)	(dollars/hr.)	(costs per dry ton of sludge applied)		
2.5	$10	$16.87	$16.68	$16.58
	15	21.06	20.75	20.60
5.0	10	16.71	16.51	16.42
	15	20.90	20.58	20.43
7.5	10	16.64	16.46	16.36
	15	20.83	20.53	20.38
10.0	10	16.62	16.43	16.33
	15	20.82	20.50	20.35

1/ Effects on subsoil injection are essentially the same.

2/ Wage rate includes fringes, by assumption.

Table 26. The Effect of Changing Interest Rates on the Cost of Surface Vehicular Application of Liquid Sludge.

Interest Rate	Annual Sludge Volume, mg.		
	50	250	500
	(added cost per dry ton of sludge applied)		
10%	$0.39	$0.42	$0.43
15%	1.08	1.16	1.20

Subsoil Vehicular Application

Base-Level Costs

In almost all respects, subsurface application (or subsoil injection) is nearly identical to surface vehicular application. The only differences are that the sludge goes underground rather than on the surface, and the equipment is slightly more expensive. The sludge can be injected using the Big Wheels "No Trac Pac" liquid sludge applicator with knife attachments for injecting sludge. The assumed price of equipment is $58,400 instead of $53,400, used in calculating the surface vehicular application cost.

Table 27 summarizes the subsoil injection costs.

Table 27. Costs of Subsoil Injection of Liquid Sludge (Base Levels)[1/].

Sludge Volume		Loading Rate, Dry Tons per Acre			
		2.5	5.0	7.5	10.0
(mg/year)		(total costs in thousands of dollars)			
50	Total	$ 143.10	$ 141.70	$ 141.20	$ 141.00
	PDT[2/]	17.14	16.98	16.92	16.90
250	Total	707.60	100.60	698.30	697.10
	PDT	16.96	16.79	16.74	16.71
500	Total	1,407.60	1,393.70	1,389.00	1,386.70
	PDT	16.87	16.70	16.64	16.62

[1/]Base price assumptions include the following:
Bulldozer rental $45.00 per hour.
Price of applicator = $58,400.
Price of diesel fuel = $0.90 per gallon.
Wage rate = $10.00 per hour (fringes included).
Equipment amortized at 7 percent.

[2/]Per Dry Ton.

Sensitivity Analysis

Like spray irrigation and surface vehicular application, subsoil injection is fairly insensitive to changes in loading rate and sludge volume. The variation that does exist is wholly attributable to changes in the cost of short-term storage.[1/] The higher the loading rate, the less storage pits required (given sludge volume), which reduces application costs. The only other cost factor, not included in application cost, that changes appreciably with different loading rates is the cost of the land required. Land costs are discussed in later sections.

The cost of subsoil injection closely resembles that of surface vehicular application in terms of its sensitivity to variables like fuel cost, wage rate, equipment price, and interest rate. Since the applicator costs a little more, the injection costs are slightly more sensitive to equipment price and interest rate than is surface vehicular application. The effects are not markedly different, however, so no detailed sensitivity analysis is presented here.

[1/] There may be economies in short term application associated with use of portable storage trucks or nurse tankers.

Dewatered Vehicular Sludge Application

Base-Level Costs

Dewatered sludge, assumed to be a vacuum filtercake or centrifuged product, cannot be pumped or sprayed. It can be spread, however, with a sludge applicator or manure spreader. The dewatered sludge applicator used in the SLUDGE model is manufactured by the same company that makes the liquid sludge applicator, Big Wheels, Inc. This equipment differs from the liquid sludge unit in that it has an open bed instead of a tank, and cannot load itself. A front-end loader is required. The costs used in the SLUDGE model were based on information on John Deere Co. loaders, but there are many other brands available.

Because dewatered sludge does not flow, short term field storage is simply a matter of piling the sludge rather than building ponds. Hence, no pits are dug, and no storage costs are included. Because there are no storage costs assumed, there is no variation in cost due to different loading rates, and application costs shown in Table 28 are for different sludge volumes alone.

As was the case in truck and rail transportation, dewatered sludge is cheaper to deal with than liquid sludge. Dewatered sludge land application costs are cheaper, on a per-dry-ton basis, than any form of liquid sludge land application.

Table 28. Costs of Vehicular Application of Dewatered Sludge (Base Level)[1/].

Application Cost	Sludge Volume, 100 Cubic Yards per Year		
	50	250	500
Total ($ thousand)	$52.00	$183.20	$366.30
Per Dry Ton	5.60	3.95	3.95

[1/]Base price assumptions include the following:
Price of applicator = $48,400.
Price of diesel fuel = $0.90 per gallon.
Price of front-end loader = $50,000.
Wage rate = $10.00 per hour (fringes included).
Equipment amortized at 7 percent.

Sensitivity Analysis

Dewatered sludge application is less sensitive to changes in fuel price than is liquid sludge high flotation application. A rise of 33 percent in fuel price increases application costs by about 8 percent, when the equipment is used to capacity. In the dewaterd sludge application, a front-end loader is also used, and the effect of fuel price on the cost of loader operation is included (Table 29).

Table 29. The Effect of Changing Fuel Price on the Cost of Vehicular Application of Dewatered Sludge[1/].

Fuel Price	Annual Sludge Volume, Cubic Yards		
	50,000	250,000	500,000
($/gal.)	(cost per dry ton of sludge applied)		
$0.90	$5.60	$3.95	$3.95
1.20	6.05	4.28	4.28

[1/]Since no field storage is required, cost per dry ton is the same for all loading rates.

The effect of changing the wage rate is moderate (Table 30). An increase of 50 percent in the wage rate leads to approximately a 25 percent increase in the cost of dewatered sludge application.

The dewatered sludge applicator costs less than either liquid

Table 30. The Effect of Changing Wage Rate on the Cost of Vehicular Application of Dewatered Sludge.

Wage Rate[1/]	Annual Sludge Volume, Cubic Yards		
	50,000	250,000	500,000
($/hour)	(cost per dry ton of sludge applied)		
$10	$5.60	$3.95	$3.95
15	7.10	4.94	4.94

1/ Wage rate includes fringes.

sludge unit, and the cost of dewatered sludge application is slightly less sensitive to equipment prices except at very low sludge volumes where equipment cannot be fully utilized. A 40 percent change in the price of the liquid sludge applicator is required to produce a 7 percent change in applicator cost, whereas a 55 percent change in applicator vehicle price is required to produce the same 7 percent change in dewatered sludge application cost (Table 31).

The dewatered sludge applicator vehicle costs less than either liquid sludge applicator. As a result, changes in the interest rate applied to the applicator's purchase have a smaller effect on dewatered sludge application costs than on liquid sludge application costs (Table 32).

Table 31. The Effect of Changing Equipment Price on the Cost of Landspreading Dewatered Sludge Application.

Equipment Price	Annual Sludge Volume, Cubic Yards		
	50,000	250,000	500,000
	(cost per dry ton of sludge applied)		
Applicator			
$48,400	$5.60	$3.95	$3.95
75,000	5.92	4.22	4.22
Front End Loader			
50,000	5.60	3.95	3.95
75,000	5.82	4.06	4.06

Table 32. The Effect of Changing Interest Rates on the Annual Cost of Dewatered Sludge Application.

Interest Rate	Annual Sludge Volume, Cubic Yards		
	50,000	250,000	500,000
	(added cost per dry ton of sludge applied)		
10%	$0.25	$0.08	$0.08
15%	0.70	0.23	0.23

Land Cost

One cost which may be incurred with any application is the cost of land. Land is different from other cost components. Equipment, fuel, labor, and other components of transportation or application are things which are used up. Land, however, can yield income. One of the major reasons that sludge is used on agricultural land is because the sludge can increase the crop yields, and hence land value or farm revenue. The same may be true of forest land. There is some indication that sludge application on forest sites may improve tree growth, although this is not always true. While growth response may not result in enough increased volume to completely offset the land costs of sludge disposal in forests, it can provide an incentive to consider the land disposal option.

The amount of land required depends on how much sludge is applied, the loading rate, and how much area (if any) is required to buffer the sludge disposal site from neighboring lands. State regulations on buffers vary, some states requiring none and others requiring several hundred feet of buffer between the disposal site and such things as public water supplies, homes, or croplands (Morris and Jewell, 1976). Since buffer requirements are site specific, they are not treated in this analysis. If buffers are needed, the land costs per dry ton of sludge treated will obviously rise.

Purchasing land in order to dispose of sludge may be unnecessary. Both private and public landowners may be willing to permit sludge application on their lands for the same reasons that farmers accept sludge: it improves the crop. Land purchase is by no means an unavoidable cost, and disposal options on other ownerships should be explored before buying land, unless the municipality is interested in growing timber for other purposes.

Tables 33 and 34 list the acreage requirements and land costs associated with different financing schemes. Doubling the loading rates halves the per-dry-ton land cost and the number of acres needed. Doubling the sludge volume, given the loading rate, doubles the total land cost, but does not change the cost per dry ton. Lengthening the amortization period moderately decreases annual costs. The interest rate has a much greater effect, as shown in the examples in Table 34. The important thing is that these costs only represent land purchase; they are not adjusted to include any land management other than waste disposal. Some of the cost of land can, for example, be offset if timber or some other crop is harvested and sold. Taxes are also left out. Finally, it is important to note that land may not have to be bought, or leased; it may be possible to apply wastes to public or private land at no cost to the waste manager if the landowner is willing to permit waste disposal or desires to use sludge to improve forest growth.

The costs shown here are only for the purpose of illustrating the effects of sludge volume, loading rate, interest rate, and amortization period on annual total and per-dry-ton costs. Land prices vary a great deal, as do tax structures, and crop and growth response to sludge application. Thus, no attempt was made to represent "average" conditions.

Table 33. Land Requirements and Costs[1/], Land Application of Liquid Sludge.

Item (dry ton per acre)	Sludge Volume and Loading Rate											
	50.0 mg.				250.0 mg.				500.0 mg.			
	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0
Acres Required	3,338	1,669	1,113	835	16,690	8,345	5,564	4,173	33,380	16,690	11,127	8,345
20 yr. Amortization Annual Cost,												
Total ($M)	157.5	78.8	52.5	39.4	787.7	393.9	262.6	197.0	1,575.4	787.7	525.2	393.9
PDT	18.88	9.44	6.29	4.72	18.88	9.44	6.29	4.72	18.88	9.44	6.29	4.72
30 yr. Amortization Annual Cost,												
Total ($M)	134.5	67.2	44.8	33.6	672.5	336.2	224.2	168.1	1,345	672.5	448.3	336.2
	16.12	8.06	5.37	4.08	16.12	8.06	5.37	4.03	16.12	8.06	5.37	4.03
50 yr. Amortization Annual Cost,												
Total ($M)	120.9	605	40.3	30.3	604.7	302.3	201.6	151.2	1,209.4	604.7	403.1	302.3
PDT	14.49	7.25	4.83	3.63	14.49	7.25	4.83	3.62	14.49	7.25	4.80	3.62

[1/]Assumes land price of $500 per acre, amortized at 7 percent.

Table 34. The Effect of Changing Interest Rates on Land Costs[1/].

Interest Rate	Amortization Period, Years		
	20	30	50
	(dollars per dry ton)		
7%	$ 9.44	$ 8.06	$ 7.25
10%	11.75	10.61	10.09
15%	15.98	15.23	15.02

[1/]Assumes land costs $500 per acre, 5.0 dry tons per acre loading rate. The costs per dry ton do not change with different sludge volumes; total costs increase at the same rate sludge volume increases.

GROUNDWATER MONITORING SYSTEM

Base-Level Costs

Table 35 presents the base-level groundwater monitoring costs. As expected, the lower the sludge volume, the greater the per-dry-ton monitoring costs. The assumed three wells may not be necessary if sludge volumes are small. At a loading rate of 10 dry tons per acre, less than 750 acres are required annually to apply 50,000 cubic yards of dewatered sludge, and one well, on-site or down-groundwater gradient, may suffice.

These monitoring costs are on the same order of magnitude as those experienced in a study of costs of forest land sludge disposal in the state of Washington (Edmonds and Cole, 1980). The Washington study, however, does not use groundwater monitoring wells, but suction lysimeters, and so represents in a narrow sense a different monitoring technology. Used properly, however, either system should be capable of providing adequate warning if a critical element in the water draining from the application site reaches unacceptable levels.

Table 35. Groundwater Monitoring Costs for Land Application of Liquid or Dewatered Sludge (Base Levels)[1].

	Cubic Yards			Million Gallons		
	50,000	250,000	500,000	50	250	500
Total	$7,580	$7,580	$7,580	$7,580	$7,580	$7,580
Per Dry Ton	.82	.16	.08	.91	.18	.09

Sensitivity Analysis

Groundwater monitoring costs are most sensitive to the cost of wells (Table 36). At $12 per foot, a 200 foot well costs $2,400, making up almost 95 percent of the monitoring costs, assuming one complete anlaysis per year and 2 hours of sample collection time by a technician.

By assumption, there are no economies of scale (or depth, as the case may be) is well drilling. Doubling well depth has exactly the same effect on monitoring cost as doubling the number of wells, and results in anincrease of around 95 percent in groundwater monitoring cost. An increase in the cost of drilling will cause exactly the same cost impact as increasing well depth or the number of wells.

No variable other than well costs (number of wells, drilling, costs, and depth) has an appreciable impact on the total cost of groundwater monitoring. The combined effect of increases in the costs of sample analysis, technician wage, and the number of samples per well is negligible. Hence, the results of sensitivity testing on these cost components is not presented here.

Table 36. The Effect of Changing the Number of Wells on Groundwater Monitoring Costs.

Number of Wells	Cost	Sludge Volume					
		Cubic Yards			Million Gallons		
		50,000	250,000	500,000	50	250	500
1	Total	$2,550	$2,550	$2,550	$2,550	$2,550	$2,550
	PDT	.27	.05	.03	.31	.06	.03
3	Total	7,580					
	PDT	.82	.16	.08	.91	.18	.09
6	Total	15,143					
	PDT	1.63	.33	.16	1.81	.36	.18
12	Total	30,268					
	PDT	3.26	.65	.33	3.63	.73	.36

1/ Per dry ton.

MULTIMODAL SYSTEM COSTS

SLUDGE was designed to calculate costs of individual components of transportation, application, and monitoring. In any given situation, a waste manager may choose to use, for example, only one kind of application, and two or more forms of transportation. As mentioned previously, pipelines are the least flexible form of transportation. If the application sites are dispersed, it may be infeasible to transport sludge to them with pipelines. The same is true of barge and rail systems, though usually to a smaller degree. Trucking is very flexible with respect to route and destination.

However, trucking is also expensive, particularly over long distances. The waste manager may wish to combine transportation systems in order to get the optimum combination of flexibility and cost. For example, the manager may find acceptable sites 90 miles from the plant spanning a few townships. Assuming he has 50 million gallons of sludge to dispose of annually, he may choose to use pipe or barge transport to a depot 80 miles away, and use trucks to carry the sludge the last 10 miles to individual sites. Truck transport alone would cost approximately $300 per dry ton, whereas the combination (with either barge or 6" pipe) would cost less than $240 per dry ton.

The model can simply be rerun to represent the two sets of conditions--80 mile haul and 10 mile haul--and the results added in order to calculate multimodal system costs.

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APPENDICES

APPENDIX A

THE LEGAL CONTEXT OF SLUDGE DISPOSAL

The Federal Water Pollution Control Act amendments of 1972 (PL 92-500) set in motion a comprehensive effort to clean up America's waterways. The goal was elimination of the discharge of pollutants into navigable waters by 1985. PL 92-500 provided not only goals and timetables but funds to be used for achieving the goals. However, PL 92-500 was not, by itself, adequate to accomplish the restoration and preservation of clean watercourses. In addition, there were inconsistencies within the act which tended to discourage the use of less energy and capital intensive waste treatment systems and the recycling of nutrients in waters, things which the act ostensibly advocated. Thus, PL 92-500 was only the beginning of the legislative effort to clean up the nation's waters.

The principal pieces of national legislation which relate to land disposal of sludge are the clean water act amendments of 1977 and the Resource Conservation and Recovery Act (RCRA) of 1976. The Clean Water Act (CWA) of 1972 essentially reiterated the goals of the Federal Water Pollution Control Act Amendments: the provision of fishable and swimmable waters by 1983, and water pollution discharge elimination of 1985. The 1977 Amendments specifically encourage alternative waste treatment processes and techniques, or

> those processes and techniques which are proven methods providing for the reclamation and reuse of water, the productive recycling of wastewater constituents and...the elimination of discharge of pollutants and finally the recovery of energy.

In addition to such alternative techniques, the amendments also encourage use of innovative waste treatment methods and processes. By encouraging innovation, the authors of the amendments hoped to assist in efforts to reduce waste treatment costs and energy requirements, while at the same time promoting the environmental and economic benefits of recycling and nutrient reuse. The Construction Grants Program under PL 92-500, the 201 Grants Program, provides the incentive to adopt both innovative and alternative technologies by providing additional federal funding for treatment plant construction to those projects making use of alternative or innovative techniques.

The CWA Amendments specifically call for the development of guidelines for the disposal and utilization of wastewater treatment plant sludge, as does the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) of 1976. Section 4004 of the RCRA asks the Administrator of the EPA to identify criteria which distinguish a sanitary waste disposal site from an "open dump," and unsanitary or unsafe waste disposal site, such that states may act to close or upgrade all such substandard facilities. These criteria establish the level of safety necessary to provide that "no reasonable probability of adverse effects on health or the environment" will result from the operation of the facility

(40 CFR Part 257). These regulations are important in determining the economic feasibility of land application, although since the regulations were published very recently, on September 21, 1979 (40 CFR, Vol. 44, No. 179), it is not yet known precisely how they will affect costs of land application operations.

The RCRA, like the CWA Amendments and the Federal Water Pollution Control Act Amendments, stresses the importance of nutrient recovery and resource or energy conservation, and provides for research and development aimed at developing appropiate techniques for achieving these goals.

In terms of regulatroy standards, the RCRA and CWA Amendments affect land disposal of sludge more extensively than any other legislation. The latest published regulations deal with Section 4004 of RCRA and partially with Section 405 of the CWA, providing guidelines for disposal of wastewater treatment plant sludge on land. Of particular importance is the fact that these regulations apply different standards to different lands; e.g. the disposal of sludge on agricultural lands is, in general, more closely controlled than disposal on lands whose crops do not normally enter the human food chain. If human food chain crops or animal feed are grown on the disposal sites, the waste manager must control cadmium loadings, soil pH, and loadings and application of polychorinated biphenyls (PCBs) in addition to observing standards which apply to all waste disposal facilities. Regulations concerning disease vector movement, groundwater and surface water pollution, endangered species habitat maintenance, and floodplain application must be observed by all facilities.

Table A-4 shows a summary of these regulations, which apply to forest land disposal sites in general. In many instances, only a few of these regulations may apply. Regulations concerning surface and groundwater pollution are probably, in most cases, the most limiting legal restrictions on sludge application to forest land. In particular, the standards for nitrate-nitrogen contamination of groundwater may be the most limiting factor, and exert the greatest influence of any of the standards listed above on the economics of forest land application. The nitrate limitation can generally be observed by proper management of sludge loading rates, applying only as much nitrogen as the requirements of the ecotype (Metcalf and Eddy, 1978).

Most municipal sludge is not considered a "hazardous waste" at present by the Environmental Protection Agency. The provisions of the RCRA allow EPA to classify it as such if "improperly treated, stored, transported, or disposed of, or otherwise managed" (Subtitle C, Section 3001, RCRA). If sludge is ever classified a hazardous waste, the RCRA could have a significant impact on the economics and feasibility of land application in general. Restrictions contained in sections dealing with site selection, enclosure and long-term care, and monitoring may increase costs by requiring certain buffer zones, soil quality, frequency of testing, and use restrictions. Other sections of the act, however, could make it almost impossible to apply the sludge to land at all, by prohibiting landfarming of persistent organics such as PCBs and hazardous components such as some heavy metals (S. 250. 55-5 (a)(3), RCRA).

Besides the Federal Water Pollution Control Act Amendments, the CWA and its Amendments, and the RCRA, there is little federal legislation directly affecting sludge application to forest land. The Safe Drinking Water Act may restrict, to some extent, the application of sludge in the recharge zones of sole source aquifers (determined to be the only or primary source of drinking water in certain areas). In general, this is no more limiting than the standards for groundwater pollution contained in the regulations implementing the RCRA.

State legislation dealing with land application of sludge varies by state from nothing to extremely restrictive. As of 1976, only 39 percent of all states and territories had some formal regulations dealing with land application (including landfilling) of sludge. Table A-5 lists these restrictions.

Tables A-1 through A-3 present the groundwater pollution criteria which must be met on any sludge disposal operation.

Table A-1. Maximum Contaminant Levels for Inorganic Chemicals.

Contaminant	Celsius[1/]	Level
		(Milligrams/Liter)
Arsenic	NA	0.05
Barium	NA	1.00
Cadmium	NA	0.010
Chromium	NA	0.05
Lead	NA	0.05
Mercury	NA	0.002
Nitrate (as N)	NA	10.00
Selenium	NA	0.01
Silver	NA	0.05
Floride	- 12	2.4
	12.1 - 14.6	2.2
	14.7 - 17.6	2.0
	17.7 - 21.4	1.8
	21.5 - 26.2	1.6
	26.3 - 32.5	1.4

[1/]Annual average of the maximum daily air temperature.

[2/]Not applicable.

Table A-2. Maximum Contaminant Levels for Organic Chemicals.

Contaminant	Level (Milligrams/Liter)
Chlorinated hydrocarbons	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.0005
Chlorophenoxys	
2,4-D	0.1
2,4,5-TP	0.01

Table A-3. Maximum Groundwater Contaminant Levels for other than Health Effects.

Contaminant	Level
Chloride	250 mg/1
Color	15 color units
Copper	1 mg/1
Foaming Agents	0.5 mg/1
Iron	0.3/1
Manganese	0.5 mg/1
Odor	3 Threshold Odor No.
pH	6.5 - 8.5
Sulfate	250 mg/1
TDS[1/]	500 mg/1
Zinc	5 mg/1

[1/]Total dissolved solids.

Table A-4. Waste Disposal Regulations Applicable to the Application of Sludge to Forest Land Not Used for Food Chain Crop Production.

Floodplains	No restriction of flow of base flood; no reduction in temporary water storage capacity of floodplain; no washout of solid waste, so as to pose a hazard to human life, wildlife, or land or water resources.
Endangered Species	No destruction or adverse modification of critical habitat of endangered or threatened species.
Surface Water	No discharge of pollutants into waters in violation of S. 402, CWA (National Pollutant Discharge Elimination System); no non-point source pollution that violates S. 208, CWA.
Groundwater	A facility or practice will not contaminate[1/] groundwater beyond the solid waste boundary, or beyond a specified by approved state regulation.
Disease	On-site population of disease vectors minimized, sludge applied to land or incorporated into soil is treated by a process to significantly reduce pathogens[2/]; public access controlled for 12 months; grazing by animals whose products are consumed by humans is prevented for 1 month.

[1/] Contamination levels are defined in Appendix I, 40 CFR, Vol. 44, No. 179.

[2/] Processes to significantly reduce pathogens are defined in 40 CFR, Vol. 44, No. 179.

Source: Criteria for classification of solid waste disposal facilities and practices; final, interim final, and proposed regulations (as corrected in the Federal Register of September 21, 1979) Part ix Environmental Protection Agency, 40 CFR 257, Thursday, September 13, 1979.

Table A-5. Summary of State Regulations and Restrictions Governing Land Application of Sludge.

State	Regulations	Buffer Zone Required	Restrictions
Alabama	No		
Alaska	No		Permit Required
Arizona	No		
Arkansas	No		
California	No		Ad Hoc Basis[1/]
Colorado	Yes	x	Allowed in Landfills
Connecticut	No		
Delaware	No		Landfill[2/] - Ad Hoc
D.C.	No		
Florida	No	x	Landfill - Ad Hoc
Georgia	No		
Guam			
Hawaii	No		
Idaho	Yes		Heat Treatment Required
Illinois	Yes	x	Ad Hoc Basis
Indiana	Yes	x	Stabilization Required
Iowa	No		Landfill if Dewatered
Kansas	Yes		Ad Hoc Basis - Landfill
Kentucky	No		Ad Hoc Basis
Louisiana	No		Ad Hoc Basis
Maine	Yes[3/]	x	
Maryland	Yes[3/]		
Massachusetts	Yes		Landfill - Ad Hoc

Table A-5 (cont'd.).

Michigan	Yes		Ad Hoc Basis
Minnesota	Yes[3/]	x	Guidelines in Preparation
Mississippi	No		Stabilization Required - Ad Hoc
Missouri	Yes		Landfill if Dewatered
Montana	Yes		Landfill if Dewatered
Nebraska	No		
Nevada	No		
New Hampshire	Yes		Permit - Ad Hoc Basis
New Jersey	Yes[3/]	x	Landfill - mix w/refuse
New Mexico	No		
New York	No	x	Ad Hoc Basis
North Carolina	No		Ad Hoc Basis
North Dakota	Yes		Landfill
Ohio	Yes		Landfill - Ad Hoc
Oklahoma	Yes[3/]	x	Landfill - Ad Hoc
Oregon	Yes	x	Landfill - Permit
Pennsylvania	Yes		Landfill - permit if digested and dewatered
Puerto Rico	No		
Rhode Island	Yes		
South Carolina	Yes		
South Dakota	No		Ad Hoc Basis
Tennessee	Yes		Dewatering Required
Texas	Yes	x	Landfill - Ad Hoc
Trust Territories			
Utah	Yes		Digestion required (or more stringent)
Vermont	Yes		Landfill - Ad Hoc
Virginia	Yes[3/]	x	Stabilization required (or more stringent)

Table A-5 (cont'd.).

Washington			
West Virginia			
Wisconsin	Yes	x	Digestion required as a minimum
Wyoming			

1/ Land disposal evaluated on an ad hoc (case by case) basis.

2/ Disposal in landfills regulated.

3/ Limits on sludge constituents that may be applied to land.

Sources: Compiled by the National Commission on Water Quality. In Municipal Sludge Management: E.P.A. Construction Grants Program: An overview of the sludge management situation. U.S. E.P.A., Office of Water Program Operations, Municipal Construction Division. April, 1976.
and
Current and Potential Utilization of Nutrients in Municipal Wastewater and Sludge. Vol. II. Metcalf and Eddy, Engineers. 21 July, 1978 (1st draft).

APPENDIX B

DESCRIPTION OF SLUDGE TRANSPORTATION SYSTEM, CWC MODEL

Land application of sludge, while not a new idea, is currently used to dispose of only 25 percent of the nation's municipal sludge (U.S.E.P.A., 1976). More importantly, only 1/5 of this amount is applied to non cropland. Moreover, much of the cropland application is not carried out by the municipality itself. In some cases, the municipality may simply allow farmers to take as much sludge as they want; in others, municipalities deliver sludge to farmers who, in turn, apply it themselves. As a result, many municipalities may be ignorant of the actual mechanics of transporting or applying their sludge to land, particularly forest land. An understanding of the procedures required in forest land disposal of sludge is necessary before a responsible waste management agency is willing to invest in such a system. The following sections describe how sludge can be transported and applied to forest land, what procedures should be followed to help insure compliance with federal regulations and guidelines, and how monitoring is done.

The Sludge

Municipal sludge contains nitrogen, phosphorous, and potassium, the principal plant nutrients. However, the quantities of these nutrients are small, as Table B-1 illustrates. Because the nutrient content

Table B-1. Nutrient and Organic Matter Constituents in Typical Digested Sludge.

Constituent	Range, % TS[1/]	Typical, % TS
Nitrogen	1.5 - 6.0	3.0 - 4.0
Phosphorus	0.8 - 4.0	2.0 - 2.5
Potassium (Potash)	0.0 - 3.0	0.4 - 0.5
Organic Carbon	27 - 32	31.0

[1/]Percentage of total solids.

is low, sludge cannot be considered a true fertilizer. It can, however, make an acceptable soil conditioner, particularly on well-drained, coarse-textured soils.

Any sludge that is not considered a hazardous waste may be applied to land, but the potential odor and health-related problems associated with application of raw sludge are probably unacceptable in the United States at present. Therefore, it must be assumed that digested sludge will be used in land treatment. Digestion can be anaerobic or aerobic. Aerobic digestion is a newer process, much less common than anaerobic.

Aerobic digestion has some advantages (EPA, 1975), but is more energy intensive and produces no usable gasses, whereas anaerobic digestion produces methane, which can and often is recovered (Metcalf and Eddy, 1978). In general, digestion involves the decomposition of organic matter, and is used to reduce odor and sludge volume, homogenize sludge solids in order to facilitate handling and disposal, reduce pathogens, produce a more easily dewaterable sludge, and store sludge to buffer disposal and dewatering practices from daily and seasonal fluctuations in wastewater flow and raw sludge production.

A typical digested sludge contains something between 1 and 10 percent solids, averaging 4 to 5 percent. A 4 percent solid sludge, which has been selected for analysis in this study, may be transported by truck, rail, pipe, or barge, and applied by spray irrigation equipment, or high-flotation tankers, with or without incorporation into the soil. Dewatered sludge, on the other hand, cannot be transported by pipe or barge, and cannot be applied by spray irrigation. There are many methods of dewatering, producing sludges with different solids contents. 20 percent solid sludge was chosen to represent dewatered sludge products for this analysis. A 20 percent solid sludge is a typical product of vacuum filtration of centrifugation, both commonly used methods of dewatering.

The Culp/Wesner/Culp Model

There are, as mentioned earlier, four modes of transport available for sludge. The ideal system has few unplanned interruptions or breakdowns, is flexible enough to accommodate changes in sludge flow and application schedules, provides flexibility in choosing terminal points for sludge delivery, is not energy-intensive, and can be implemented at reasonable cost. If one of these four methods were obviously superior in all these categories, of course, there would be no need to treat them all; however, different transport modes offer different advantages and present different problems. The best system in a particular locale depends on the circumstances of the particular waste manager.

Truck Transport

There is a wide variety of trucking equipment available currently. Trucking costs, presented in Chapter IV, are based on the following assumptions.

1. At distances of 5 to 10 miles (one way), a 1200 gallon or 15 cu. yd. diesel tank truck is used.
2. 2500 gallon or 30 cu. yd. diesel trucks are assumed for one-way haul distances of 20 to 80 miles.
3. Trucks operate for 8 hours per day. If it is possible to operate them for longer daily periods, costs can be significantly reduced.
4. Trucks and facilities are owned and operated by municipality.
5. New equipment is purchased. If used equipment can be bought, or vehicles already owned by the municipality can be used, it may be possible to reduce costs.

Figure B-1 presents the method of cost calculation used. Tables B-2 through B-5 present a summary of truck transportation system operation and management. The source of all the information in the transportation summary tables Transport of Sewage Sludge (EPA, 1977). All prices were inflated to 1979 levels using the Producer Price Index. It is assumed that trucks average 25 m.p.h. for the first 20 miles and 35 m.p.h. for the rest. A 30-minute loading time and 15-minute unloading time were assumed as well. If the turnaround time is shorter or longer, costs of truck operation will be smaller or greater, respectively. Another factor which can affect trucking costs is the number of hours of operation per day. Continuous operation is more cost effective than working 8-hour days; if continuous operation is possible, costs

Figure B-1. Cost Calculation, Truck Transport Cost

A. Point to point haul cost, \$/year.

1. Fuel =

   (Annual gallons used) X (Fuel cost/gallon)

2. Truck maintenance =

   (Annual miles) X (Cost/mile)

3. Truck driver =

   (Annual driver manhours) X (Cost/manhour, incl. fringes)

4. Total direct operation and maintenance = sum 1,2 and 3 above

5. Total operation and maintenance with overhead =

   (A4, above) X (1.25)

6. Truck amortization =

   [(total truck investment) - (residual value)] X (amortization factor) + (residual value) X (interest rate)

7. Total point to point truck haul cost = sum of A5 and A6 above

B. Facilities cost, \$/year

1. Facilities amortization (assume no residual value) -

   (facilities capital cost) X (amortization factor)

2. Facilities operation and maintenance

   a. Electricity =

      (electrical energy, kwh) X (cost/kwh)

   b. Labor =

      (labor, manhours) X (cost/manhour, including fringes)

   c. Maintenance supplies, \$

   d. Total = add a, b and c above

3. Total facilities operation and maintenace, with overhead =

   (B2, above) X (1.25)

Figure B-1 (cont'd.).

4. Facilities annual cost = sum of B1 and B3 above.

C. Total annual cost = sum of A7 and B4, above.

D. Total annual cost/dry ton-mile, one way.

1. Liquid sludge.

$$\frac{\text{Total Annual Cost}}{\left(\begin{array}{l}\text{annual vol-}\\\text{ume, gallons}\end{array}\right)\left(\frac{8.33\text{ lb.}}{\text{gallons}}\right)\left(\frac{1\text{ ton}}{2000\text{ lb.}}\right)(\%\text{ solids})} \times \frac{1}{(\text{one-way haul distance, miles})}$$

2. Dewatered sludge.

$$\frac{\text{Total Annual Cost}}{\left(\begin{array}{l}\text{annual vol-}\\\text{ume, cu. yd.}\end{array}\right)\left(\frac{27\text{ cu. ft.}}{\text{cu. yd.}}\right)\left(\frac{\$5\text{ lb.}}{\text{cu. ft.}}\right)\left(\frac{1\text{ ton}}{2000\text{ lb.}}\right)} \times \frac{1}{(\%\text{ solids})(\text{one-way haul distance, miles})}$$

Table B-2. Summary of Truck Operation, Liquid Sludge Transportation.

Annual Sludge Volume, mg.	One-Way Distance	Trips/yr.		Trucks Needed		Truck Use		Truck Fuel		Truck Operators[1/]	
		2500 gal.	2500 gal.	2500 gal.	5500 gal.	2500 gal.	5500 gal.	2500 gal.	5500 gal.	2500 gal.	5500 gal.
	(miles)					(M miles/yr.)					
1.5	5	600		1		6		1.3		0.8	
	10	600		1		12		2.7		1.0	
	20		273		1		11		3.1		0.7
	40		273		1		22		6.3		1.0
	80		273		1		44		12.6		1.7
5	5	2,000		1		20		4.4		2.5	
	10	2,000		2		40		8.9		3.4	
	20		909		1		36		10.3		2.4
	40		909		2		73		20.9		3.5
	80		909		3		145		41.4		5.8
50	5	20,000		18		200		44.4		25.3	
	10	20,000		12		400		88.9		34.1	

Table B-2 (cont'd.).

	10	20,000		12		400		88.9		34.1	
	20		9,091		9		364		104.0		23.5
	40		9,091		13		727		207.7		34.9
	80		9,091		26		1,455		415.7		57.8
150	5	60,000		24		600		133.3		75.9	
	10	60,000		34		1,200		266.7		102.3	
	20		27,273		26		1,091		311.7		70.5
	40		27,273		38		2,182		623.4		104.7
	80		27,273		76		4,364		1,246.9		173.4

1/ Based on truck operating hours plus 10%.

Table B-3. Summary of Truck Operation, Dewatered Sludge Transportation.

Annual Sludge Volume, 1000 cu. yd.	One-Way Distance, miles	Trips/yr.		Trucks Needed 1/		Truck Use 2/		Fuel 3/		Operators 4/	
		15 cu.yd.	30 cu.yd.	15 cu.yd.	30 cu.yd.	15 cu.yd.	30 cu.yd.	15 cu.yd.	30 cu.yd.	15 cu.yd.	30 cu.yd.
1.5	5	100		1		1		0.2		0.1	
	10	100		1		2		0.4		0.2	
	20		50		1		2		0.6		0.1
	40		50		1		4		1.1		0.2
	80		50		1		8		2.3		0.3
5	5	333		1		3		0.7		0.4	
	10	333		1		7		1.6		0.6	
	20		167		1		7		2.0		0.4
	40		167		1		13		3.7		0.6
	80		167		1		27		7.7		1.1
50	5	3,333		2		33		7.3		4.2	
	10	3,333		2		67		14.9		5.7	
	20		1,667		2		67		19.1		4.3

Table B-3 (cont'd.).

	40		1,667		3		133		38.0		6.4
	80		1,667		5		267		76.3		10.6
150	5	10,000		4		100		22.2		12.7	
	10	10,000		6		200		44.4		17.1	
	20		5,000		5		200		57.1		12.9
	40		5,000		7		400		114.3		19.2
	80		5,000		14		800		228.6		31.8

1/ 360 days per year, 8 hours per day.

2/ 1000 gallons per year.

3/ Assumes a 15 cu. yd., 3-axle dump truck gets 4.5 mpg; a 30 cu. yd. semi dump truck gets 3.5 mpg.

4/ 1,000 man-hours per year.

Source: EPA, 1977.

Table B-4. Truck Facilities: Capital, Operation and Maintenance Data, Liquid Sludge[1/]

Item	Annual Sludge Volume, Mg. 1.5	5	50	150
Capital Cost[2/]				
Loading pump, pipe, hose	9,181	9,181	17,138	24,483
Loading truck encl.[3/]	6,121	8,569	24,483	30,603
Truck ramp for unloading	18,362	18,362	61,206	91,810
Unloading truck encl. and office	12,241	12,241	24,483	36,724
Annual amortization, 7%	3,939	4,150	10,924	15,755
Operation and maintenance				
Electricity, k.w.h. (pumping, heat, light)	25,000	35,000	90,000	145,000
Maintenance supplies, $[2/]	1,836	2,448	4,284	4,897
Operation and maintenance, labor, man-hours	1,000	1,500	3,000	4,000

[1/]Assumptions: Pumps and piping sized to fill truck in 20 minutes; use plant sludge storage; gravity unloading at disposal site.

[2/]All costs updated to 1979 using Producer Price Index.

[3/]Based on $36.72/ft^2 for office and $24.48/ft^2 for truck enclosure.

Table B-5. Truck Facilities: Capital, Operation and Maintenance Data, Dewatered Sludge[1].

Item	Annual Sludge Volume, 1000 cu. yd.			
	1.5	5	50	150
Capital Cost, $[2]				
Conveyor	12,241	12,241	24,483	24,483
Loading hopper	12,241	12,241	18,362	24,483
Loading truck encl.	6,121	6,121	12,241	12,241
Truck ramp	18,362	18,362	24,483	36,724
Unloading truck encl. and office	12,241	12,241	18,362	30,603
Annual amortization	5,252	5,252	8,404	11,029
Operation and Maintenance				
Electricity, k.w.h.	22,000	32,000	82,000	135,000
Maintenance supplies, $[2]				
Operation and Maintenance	1,836	2,448	4,284	4,897
Labor, man-hours	1,000	1,500	3,000	4,000

[1] Assumptions: Equipment sized to fill truck in 20 minutes; loading hopper sized for one truck load and gravity discharge into truck; gravity unloading at disposal site.

[2] All costs updated to 1979 using Producer Price Index.

can be decreased. However, it may be impossible to apply sludge continuously unless the application site can be illuminated, thereby increasing the costs of application.

A properly managed truck transportation system is fairly reliable; no major spill or accident problems have been reported, though occasional spills do occur and must be cleaned up[1/]. Rail and barge transport are not run by the municipality, and waste managers, therefore, must depend on the safety procedures followed by the operators.

[1/] Personal communication with Maryland Environmental Service.

Barge Transport

Standard barge service uses non-self-propelled barges towed by tugboats. Some self-propelled barges are available, but they generally require larger crews and have a less versatile power unit, and therefore are less well suited to dealing with changing traffic, locks or bridges, tides and currents. Loading and unloading can be accomplished using either gravity pipeline or pumping through pipelines from storage; pumping is assumed here. A loading time of 5 hours is assumed, though loading can be accomplished in less than half this amount of time, depending on circumstances.

SLUDGE assumes that barges are owned by the waste management agency, while towing is contracted. Costs are based on purchasing all equipment new; it may be possible to reduce costs if used equipment in good condition can be obtained. Figure B-2 and Tables B-6 and B-7 summarize the barge transportation system operation and the method of cost calculation used in the CWC model.

Figure B-2. Cost Calculation, Barge Transportation.

A. Point to point haul cost, $/year

1. Barge maintenance =

   (Maintenance cost, $/year) X (Number of barges)

2. Towing cost =

   (Tug billing time, hr/yr.) X (Tug billing rate, $/hour)

3. Barge amortization =

   (Number of barges) X (Barge capital cost[1/], $)

4. Total annual point to point haul cost = sum of A1,2 and 3 above

B. Facilities cost, $/year

1. Facilities amortization (assume no residual value) =

   (Facilities capital cost)(amortization factor)

2. Facilities operation and maintenance

   a. Sludge holding and pumping maintenance =

      (Labor, manhours) X (Cost/manhour, with fringes, $/manhour)

   b. Sludge holding and pumping maintenance supplies, $

   c. Sludge holding and pumping operation =

      (Labor, manhours/trip) X (Barge trips/year) X (Cost/manhour, with fringes, $/manhour)

   d. Dock maintenance, $

   e. Electricity =

      (Electrical energy, k.w.h.) X (Cost, $/k.w.h.)

[1/]Assume no residual value at the end of 20-year life.

Figure B-2 (cont'd.).

f. Total direct facilities operation and maintenance = sum of B2a, b, c, d and e above

3. Total facilities operation and maintenance plus overhead and supervision

(B2f, above) X (1.25)

4. Facilities annual cost = sum of B1 and B3, above

C. Total annual cost = Sum of A5 and B4, above

D. Total annual cost, \$/dry ton-mile, one way =

$$\frac{\text{Total annual cost, \$}}{\left(\begin{matrix}\text{annual vol-}\\\text{ume, gal.}\end{matrix}\right)\left(\begin{matrix}\text{8.33 lb.}\\\text{per gal.}\end{matrix}\right)\left(\frac{\text{ton}}{\text{2,000 lb.}}\right)(\text{\% solids})\left(\begin{matrix}\text{one-way haul}\\\text{distance, miles}\end{matrix}\right)}$$

Table B-6. Summary of Barge Operation, Liquid Sludge Transportation.

Annual Sludge Volume, mg.	One-way Distance, Miles	500,000-gal. Barges Required	Trips/ Year	Tug Billing Time, hr./yr.	Tug Fuel Calculation Time, Days/year
7.5	20	1	15	259	7
	40	1	15	431	14
	80	1	15	776	28
	160	1	15	1,466	56
	320	1	15	2,846	112
75	20	1	150	2,588	70
	40	1	150	4,310	140
	80	1	150	7,760	280
	160	2	150	14,660	560
	320	3	150	28,460	1,120
150	20	1	300	5,180	140
	40	1	300	8,630	280
	80	2	300	15,530	560
	160	4	300	29,330	1,120

Table B-6 (cont'd.).

	320	6	300	56,930	2,240
750	20	4	1,500	25,880	700
	40	6	1,500	43,100	1,400
	80	9	1,500	77,600	2,800
	160	16	1,500	146,600	5,600
	320	30		248,600	11,200

Table B-7. Barge Facilities: Capital, Operation and Maintenance, Data, Liquid Sludge[1/].

Item	Annual Sludge Volume, mg.			
	7.5	75	150	750
Capital Cost, $[2/]				
Sludge Storage at loading facility	124,861	308,480	308,480	495,772
Loading and Unloading Pump.	95,482	188,516	188,516	188,516
Loading and Unloading Pipe	24,483	48,965	48,965	48,965
Loading and Unloading Docks and facilities	244,826	244,826	244,826	367,238
Annual Amortization, 7%	42,017	67,857	67,857	94,433
Annual Operation and Maintenance				
Maintenance, manhours	680	1,640	1,640	2,400
Operation, manhours/barge load	12	12	12	12
O & M Supplies, $	5,141	15,424	15,424	24,483
Dock maintenace, $	7,345	7,345	7,345	12,241
Electrical energy, k.w.h.	35,000	90,000	140,000	480,000

[1/]Assumptions: Pumps and piping sized to fill barge in 4 hours; storage at plant to equal one day's

Table B-7 (cont'd.).

sludge production or two barge loads minimum; 24-hour, 360 day annual operation as needed.

[2/] All costs updated to 1979 using Producer Price Index.

Rail Transport

Rail transportation costs may vary a great deal from region to region in the United States. The rate charged to a shipper depends on the tonnage of material to be moved and the shipping distance. Table B-8 shows the average national 1975 rate structure, which the SLUDGE model updates to 1979 using the Producer Price Index. 20,000-gallon tank cars for liquid sludge transportation are assumed here to be leased from the manufacturer on a full-maintenance basis. In addition, the C/W/C model assumes (waste management) agency ownership of railroad loading and unloading facilities, where facilities costs are included. Hopper type cars used for dewatered sludge transportation are assumed to be provided by the railroad.

Railways have been used very infrequently in sludge transportation, and railroad companies are not usually willing to share rate information with researchers, according to the C/W/C model. Thus, since there are few working examples to draw from, the cost information in the C/W/C model is probably less accurate than information concerning other transport systems.

Cost calculation methods and rail system operating characteristics follow, Figure B-3, and Table B-9 through B-13.

Table B-8. Railroad Shipping Rates, 1975 Levels.

One-way Distance, Miles	Rate, $/ net ton	Remarks
20	$ 2.10	Railroads, as of 1975, generally allowed rebates of $0.06 yo $0.20 per mile per car if shipper owns cars. C/W/C model assumes $0.15.
40	3.00	
80	4.10	
160	6.50	
320	12.50	

Figure E

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Figure B-3. Cost Calculation, Rail Transportation.

A. Point to point haul cost, dewatered sludge, \$ per year

(Annual sludge volume, cu.yd.) X $\left(\frac{27\ ft.^3}{cu.yd.}\right)\left(\frac{55\ lb.}{cu.ft.}\right)\left(\frac{1\ ton}{2000\ lb.}\right)$ X $\left(\begin{matrix}\text{Rail rate,}\\ \text{\$/ton}\end{matrix}\right)$

B. Point to point haul cost, liquid sludge, \$/year

1. Railroad charges

   (Annual sludge volume, mg.) X (8.33×10^6 lb./mg.) X

   $\left(\frac{ton}{2000\ lb.}\right)$ X $\left(\begin{matrix}\text{Rail rate,}\\ \text{\$/ton}\end{matrix}\right)$

2. Railroad mileage credit (for shipper-supplied cars)

   (Round trip haul distance, miles) X (Trips/year) X (Railroad mileage credit, \$/mile)

3. Rail tank car leasing (including maintenance)

   (Number of tank cars required) X (Annual full-maintenance lease rate, \$)

4. Total annual point to point haul cost, liquid sludge.

   Sum of B1 and B3, minus B2, above

C. Facilities cost, \$/year

1. Facilities amortization

   (Facilities capital cost, \$) X (Amortization factor)

2. Facilities operation and maintenance

   a. Sludge holding and pumping maintenace, \$

      (Labor, manhours) X (Cost, \$/manhour, with fringes)

   b. Sludge holding and pumping supplies, \$

   c. Sludge holding and pumping operation

      (Labor, manhours) X (Cost, \$/manhour with fringes)

Figure B-3 (cont'd.).

d. Rail maintenance, \$

e. Electrical energy

(Electrical energy, k.w.h.) X (Cost, \$/k.w.h.)

f. Total direct facilities operation and maintenance

Sum of 2a-e, above

3. Total facilities operation and maintenance with overhead and supervision

(Total direct facilities O & M cost, \$) X (1.25)

4. Facilities annual cost

Sum of C1 and C3, above

D. Total annual cost

1. Dewatered sludge

Sum of A and C4, above

2. Liquid sludge

Sum of B4 and C4, above

E. Total annual cost, \$/dry ton-mile one way.

1. Dewatered sludge

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{l}\text{Annual}\\ \text{Sludge}\\ \text{Volume,}\\ \text{cu.yd.}\end{array}\right) \times \left(\frac{\text{27 cu.ft.}}{\text{cu.yd.}}\right) \times \left(\frac{\text{55 lb.}}{\text{cu.ft.}}\right) \times \left(\frac{\text{1 ton}}{\text{2000 lb.}}\right) \times \left(\frac{\text{Percent Solids}}{100}\right)}$$

$$\frac{1}{\text{(One way haul distance, miles)}}$$

2. Liquid Sludge

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{l}\text{Annual}\\ \text{Volume,}\\ \text{gal.}\end{array}\right) \times \left(\frac{\text{8.33 lb.}}{\text{gal.}}\right) \times \left(\frac{\text{1 ton}}{\text{2000 lb.}}\right) \times \left(\frac{\text{Percent solids}}{100}\right) \times \left(\begin{array}{l}\text{one way}\\ \text{haul dis-}\\ \text{tance,}\\ \text{miles}\end{array}\right)}$$

Table B-9. Railroad Operation Summary, Liquid Sludge.

Annual Sludge Volume, mg.	One-way Distance, Miles	Annual Carloads	Load and Unload Time, Hours	Round Trip Time, Hours	Cars Required
7.5	20	375	5	106	5
	40	375	5	106	5
	80	375	5	154	7
	160	375	5	178	8
	320	375	5	202	9
75	20	3,750	6	108	47
	40	3,750	6	108	47
	80	3,750	6	156	68
	160	3,750	6	180	78
	320	3,750	6	204	89
150	20	7,500	7	110	97
	40	7,500	7	110	97
	80	7,500	7	158	139
	160	7,500	7	182	160

Table B-9 (cont'd.).

	320	7,500	7	206	181
750	20	37,500	19	134	581
	40	37,500	19	134	581
	80	37,500	19	182	789
	160	37,500	19	206	893
	320	37,500	19	230	997

Table B-10. Railroad Operation Summary, Dewatered Sludge.

Annual Sludge Volume, cu.yd.	Car Size, cu.yd.	Annual Carloads
7.5	150	150
15	50	300
75	100	750
150	100	1,500
750	100	7,500

Table B-11. Regional Variations in Rail Rates.

Area	Rate Variation
North Central, Central	Average, as outlined herein
Northeast	25% higher than average
Southeast	25% lower than average
Southwest	10% lower than average
West Coast	10% higher than average

Table B-12. Railroad Facilities: Capital, Operation and Maintenance Data, Liquid Sludge[1/]

Item	Annual Sludge Volume, mg.			
	7.5	75	150	750
Capital Cost, $[2/]				
Sludge storage at loading facility	37,948	124,861	176,274	495,772
Loading pumping	46,517	82,017	94,258	99,154
Loading piping and appurtenances	12,241	59,982	61,206	61,206
Loading and unloading rail sidings and switches	45,293	97,930	190,964	455,376
Loading and unloading bldg. and site work	78,344	102,827	166,481	303,584
Annual amortization, 7%	18,908	40,127	59,139	121,429
Annual Operation and Maintenance:				
Maintenace, manhours	130	340	500	1,200
Operation, manhours	4,124[3/]	9,000[4/]	10,500[4/]	28,500[4/]
O & M supplies, $	581	2,738	4,450	12,241
Rail maintenance, $	2,248	4,897	9,793	24,483

Table B-12 (cont'd.).

Electrical energy, k.w.h.	35,000	90,000	140,000	480,000

1/ Assumptions: Pump and pipe sized to fill 2, 10, 20 and 100 unit car trains in 1.5, 2, 3, and 15; rail cars discharge by gravity into unloading storage.

2/ All prices updated to 1979 using Producer Price Index.

3/ One man for total load and unload time.

4/ Two men for total load and unload time.

Table B-13. Railroad Facilities: Capital, Operation and Maintenance Data, Dewatered Sludge1/

Item	Annual Sludge Volume, mg.			
	7.5	75	150	750
Capital cost, $2/				
Loading sludge hoppers	27,279	34,276	68,551	137,102
Loading conveyors	24,483	24,483	49,965	97,930
Loading and unloading rail switches and sidings	45,293	45,293	89,361	315,825
Loading and unloading bldg. and site work	78,344	78,344	102,827	195,860
Annual amortization, 7%	15,231	15,652	26,576	64,076
Annual Operation and Maintenance:				
Maintenance, manhours	130	340	500	1,200
Operation, manhours	1,6503/		4,1253/	10,0004/
O & M supplies, $	581	2,738	4,450	12,241
Rail maintenance, $	2,448	2,448	4,897	30,603

Table B-13 (cont'd.).

Electrical energy, k.w.h.	92,000	92,000	169,000	308,000

1/ Assumptions: Loading storage hopper sized for one carload; gravity loading from storage hopper; rail cars dump by gravity into unloading storage.

2/ All prices updated to 1979 using Producer Price Index.

3/ One man for total load and unload time.

4/ Two men for total load and unload time.

Pipeline Transport

Pipes can transport raw as well as digested sludge, but may add to pipeline maintenance costs due to grease buildup. In addition, disposal of raw sludge by landspreading is generally not done in the United States, primarily because of pathogen considerations. Accordingly, the costs of pipeline transport were based on moving only digested sludge with 0 to 4 percent solids. Pumps needed for pipeline transport were assumed to be non-clog slurry centrifugal type pumps operating at 1,780 r.p.m. It may be possible to cut pipeline transport marginally by selecting a different size pump based on the pipe size, terrain, and design of the pipeline-route, but these considerations are site-specific. Hence, the Culp/Wesner/Culp model does not attempt to optimize pumping. Four and six-inch pipes require more pumps in series in each pumping station, due to the greater friction loss associated with smaller pipes. Two pumps operating in parallel are assumed for 16, 18, and 20 inch pipelines to accommodate higher flows.

Pipelines are assumed to be cement lined cast iron or ductile iron, in accord with typical operations. Installation was assumed to be above hard rock, in typical soil conditions. The costs were based on one major highway crossing per mile, on single track railroad crossing every five miles, and several minor road/driveway crossings per mile. When the number of crossings is increased, the construction cost of pipelines will also increase. Crossings represent a major cost of small pipeline construction, and if many more crossings are encountered than are assumed here, the costs shown will not be relevant.

The pipeline burial depth may affect the pipeline transportation cost if the depth exceeds 3 to 6 feet of normal soil. The costs should be increased approximately 15 percent for burial depths up to 10 feet.

Pipeline transportation costs are based on agency ownership and operation of all portions of the system. The following figures and tables illustrate the operation and cost calculation of the pipeline transportation system.

Figure B-4. Cost Calculation, Pipeline Transport.

A. Determine pipeline size from project information

B. Pipeline capital cost, $/year

1. Pipeline

   (Pipeline length, ft.) X (Unit cost, $/ft.)

2. Extra railroad crossings, $ (if more than one per 5 miles)

   (Rail crossings) X (Unit cost, $)

3. Major road crossings, $

   (Major road crossings) X (Unit cost, $)

4. Pipeline amortization

   (Sum of B1-3, above) X (amortization factor)

C. Pumping station capital amortization and operation and maintenance, $/year

1. Electrical energy

   (Cost, $/k.w.h.) X (Annual k.w.h./ft. head) X [(Pipeline length, 100 ft.) X (hydraulic loss, ft/100' of pipe) + (pipeline elevation change, ft.)]

2. Number of pumping stations

   $$\frac{\text{(Total system head, ft.)}}{\text{(Head per pumping station)}}$$

3. Operation and maintenance labor

   (No. of pumping stations) X (O & M, manhours) X (Cost, $/manhour, with fringes)

4. Operation and maintenance supplies and parts, $

5. Total operation and maintenance with overhead and supervision

   (Sum of C1, 3, and 4, above) X (1.25)

Figure B-4 (cont'd.).

6. Pumping station amortization

(Number pump. stations) X (Cost/station, \$) X (Amortization factor)

D. Total annual Cost

(Sum of B4 and C6, above

E. Total annual cost, \$/dry ton-mile

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{l}\text{Annual}\\ \text{Volume,}\\ \text{gal.}\end{array}\right)\left(\frac{8.33\ \text{lb.}}{\text{gal.}}\right)\left(\frac{\text{ton}}{2000\ \text{lb.}}\right)\left(\frac{\text{percent solids}}{100}\right)\left(\begin{array}{c}\text{pipeline length,}\\ \text{miles}\end{array}\right)}$$

Table B-14. Pipeline Sludge Flow and Volume.

Pipeline size, inches	Sludge flow rate, gpm[1/] @ 3 fps[2/] velocity	Pipeline capacity at 3 fps velocity (daily hours of operation)		
		48	12	20
		(capacities in mgd[3/])		
6	280	0.13	0.20	0.34
10	800	0.38	0.58	0.96
14	1,400	0.67	1.01	1.68
18	2,500	1.20	1.80	3.00

1/ gallons per minute

2/ feet per second

3/ million gallons/day

Table B-15. Pipeline Sludge Pumping Characteristics.

Pipeline size, in.	Hydraulic loss. ft./100ft.	Approximate need available at each pumping station, ft.	Pump Efficiency, %	Pump Station Cost, $	Pumping station spacing, ft.[1/]
6	1.40	450[2/]	50	69,775[4/]	32,143
10	0.82	230	64	107,723	28,049
14	0.45	210	78	150,568	46,667
18	0.39	225[3/]	76	226,464	57,179

[1/] Assumes level terrain.

[2/] Pumps in series for additional head.

[3/] Pumps in parallel for additional capacity.

[4/] Updated to 1979 using Producer Price Index.

Table B-16. Pipeline Energy, Operation, and Maintenance Cost.

Pipeline Size, inches[1/]	Power, KW/1000 g.p.h.-ft. head	Annual O & M labor, manhours pumping station	Annual O & M parts and supplies $/pump. station	Pipeline Cost $/ft.[2/]
6	.0070	720	670	16.25
10	.0055	820	820	19.25
14	.0045	870	940	23.75
18	.0046	940	1,750	28.25

1/ For short pipelines, use operation and maintenance labor and supplies cost for one pumping station as a minimum.

2/ Costs for installed pipelines buried 3-6 feet; add 15 percent for 6-10' depth; add 70 percent for hard rock excavation.

APPENDIX C

SOURCE LISTING OF SLUDGE MODEL

```
?100-5700
 PROC
 PRI
 FOR
  REA
  PRI
   IF
  PRI
  FOR
  REA
   PR
   PR
   FO
   PR
    DI
   PR
   FO
   RE
    TR
    AN
    AN
    PR
    P
    TR
    TR
    ZI
    BI
    AN
    PR
    PR
    RE
    IF
    IF
    GO
    IF
    IF
    BR
    PR
    TR
    GO
   IF
   BR
   PR
   TR
   GO
   IF
   BR
   PR
   TR
   GO
   IF
   BR
   PR
   GO
   BR
   PRI
   GO
   IF
   BR
   PRI
   TRU
```

```
LIST 100-5700
      PROGRAM SLUDGE(INPUT,OUTPUT)
      PRINT 5
5     FORMAT (◆ IS SLUDGE LIQUID OR SOLID (1=LIQUID,2=SOLID)?    ◆)
      READ◆,IFORM
      PRINT 265
      IF(IFORM.EQ.2)GO TO 15
      PRINT 10
10    FORMAT (◆ SLUDGE VOLUME IN GALLONS PER YEAR IS    ◆)
      READ ◆, SLVOL
      PRINT 265
      PRINT 6
6     FORMAT (◆ LIQUID SLUDGE TRANSPORTATION TESTING◆)
      PRINT 265
      DSVOL=SLVOL◆.04◆8.345/2000.
120   PRINT 20
20    FORMAT(◆ THE AVERAGE ONE-WAY HAUL IN MILES IS    ◆)
      READ◆,DIST
      TRUCK=0.
      ANFUEL=0.
      ANHOUR=0.
      RAIL=0.
      PIPE=0.
      TRFUEL=0.
      TRHOUR=0.
      ZLABOR=0.
      BARGE=0.
      ANBAR=0.
      PRINT 21
21    FORMAT(◆ ARE LOADING FACILITIES AVAILABLE (1=Y,2=N)?    ◆)
      READ◆,IFAC
      IF(DIST.GE.20)GO TO 25
      IF(SLVOL.LT.15000000.)GO TO 30
      GO TO 45
25    IF (IFAC.EQ.1)GO TO 35
      IF (DIST.NE.20.)GO TO 40
      BARGE = (165.50212 + 6.44827◆SLVOL/1000000.)◆1000.
      RAIL = (25.62100 + 15.72497 ◆SLVOL/1000000.)◆1000.
      TRUCK=(3.19779+13.44249◆SLVOL/1000000.)◆1000.
      GO TO 45
40    IF(DIST.NE.40.)GO TO 50
      BARGE=(89.6429 + 12.03182◆SLVOL/1000000.)◆1000.
      RAIL=(-22.05267+19.87005◆SLVOL/1000000.)◆1000.
      TRUCK=(7.2297+24.04947◆SLVOL/1000000.)◆1000.
      GO TO 45
50    IF(DIST.NE.80)GO TO 55
      BARGE=(89.02227+19.82329◆SLVOL/1000000.)◆1000.
      RAIL=(-7.03139+26.08127◆SLVOL/1000000.)◆1000.
      TRUCK=(-42.41604+43.80206◆SLVOL/1000000.)◆1000.
      GO TO 45
55    IF (DIST.NE.160.)GO TO 60
      BARGE=(-24.45808+40.419◆SLVOL/1000000.)◆1000.
      RAIL=(-147.03002+41.73004◆SLVOL/1000000.)◆1000
      GO TO 45
60    BARGE =(624.97492+75.66336◆SLVOL/1000000.)◆1000.
      RAIL=(-274.07701+70.47501◆SLVOL/1000000.)◆1000.
      GO TO 45
35    IF(DIST.NE.20)GO TO 65
      BARGE=(230.30746+7.11812◆SLVOL/1000000.)◆1000.
      RAIL=(63.08177+16.79259◆SLVOL/1000000.)◆1000.
      TRUCK=(31.74899+14.20784◆SLVOL/1000000.)◆1000.
```

```
      GO TO 45
65    IF(DIST.NE.40.)GO TO 70
      BARGE=(277.04467+11.46641*SLVOL/1000000.)*1000.
      RAIL=(112.14237+20.43976*SLVOL/1000000.)*1000.
      TRUCK=(28.44017+24.19979*SLVOL/1000000.)*1000.
      GO TO 45
70    IF(DIST.NE.80.)GO TO 75
      BARGE=(304.13095+20.27927*SLVOL/1000000.)*1000.
      RAIL=(-32.00911+28.18739*SLVOL/1000000.)*1000.
      TRUCK=(11.42112+45.46534*SLVOL/1000000.)*1000.
      GO TO 45
75    IF(DIST.NE.160.)GO TO80
      BARGE=(163.20688+41.91464*SLVOL/1000000.)*1000.
      RAIL=(182.45874+38.69922*SLVOL/1000000.)*1000.
      GO TO 45
80    BARGE=(463.05093+76.25706*SLVOL/1000000.)*1000.
      RAIL=(293.46267+72.27289*SLVOL/1000000.)*1000.
45    PRINT 85
85    FORMAT(* SELECT PIPE SIZE(6,10,14,OR 18 INCHES)    *)
      READ*,PSIZE
      IF(PSIZE.EQ.6)PIPE=2.4727*DIST*5280.
      IF(PSIZE.EQ.10)PIPE=2.7543*DIST*5280.
      IF(PSIZE.EQ.14)PIPE=3.1827*DIST*5280.
      IF(PSIZE.EQ.18)PIPE=4.1131*DIST*5280.
      IF (DIST.LE.10) GO TO 30
      GO TO 90
30    IF(IFAC.EQ.1)GO TO 95
      IF(DIST.EQ.5.)TRUCK=(5.58814+9.01913*SLVOL/1000000.)*1000.
      IF(DIST.EQ.10.)TRUCK=(1.32573+17.23976*SLVOL/1000000.)*1000.
      GO TO 90
95     IF(DIST.EQ.5.)TRUCK=(28.15495+9.38539*SLVOL/1000000.)*1000.
       IF(DIST.EQ.10.)TRUCK=(20.26666+17.95429*SLVOL/1000000.)*1000.
90     IF(DIST.EQ.5.)ANFUEL=(-.03885+.88891*SLVOL/1000000.)*1000.
       IF(DIST.EQ.10)ANFUEL=(.02230+1.77783*SLVOL/1000000.)*1000.
       IF(DIST.EQ.20.)ANFUEL=(-.03516+2.07845*SLVOL/1000000.)*1000.
       IF(DIST.EQ.40.)ANFUEL=(.02911+4.15555*SLVOL/1000000.)*1000.
       IF(DIST.EQ.80.)ANFUEL=(-.02212+8.31291*SLVOL/1000000.)*1000.
       PRINT 115
115    FORMAT(* THE PRICE OF TRUCK FUEL IS    *)
       READ*,GASPR
       GASP=(GASPR-.73)*ANFUEL
       PRINT 116
116    FORMAT(* THE HOURLY WAGE FOR TRUCKING LABOR IS    *)
       READ*,ZLABPR
       IF(DIST.EQ.5.)ANHOUR=(.00669+.50594*SLVOL/1000000.)*1000.
       IF(DIST.EQ.10.)ANHOUR=(-.01907+.68215*SLVOL/1000000.)*1000.
       IF(DIST.EQ.20.)ANHOUR=(-.00018+.46998*SLVOL/1000000.)*1000.
       IF(DIST.EQ.40.)ANHOUR=(-.00352+.69805*SLVOL/1000000.)*1000.
       IF(DIST.EQ.80.)ANHOUR=(-.01608+1.15612*SLVOL/1000000.)*1000.
       ZLABOR=(ZLABPR-9.79)*ANHOUR
       TRUCK=TRUCK+GASP+ZLABOR
       IF(DIST.EQ.20.)ANBAR=(7.82254+20.29964*SLVOL/1000000.)
       IF(DIST.EQ.40.)ANBAR=12.5821+33.83267*SLVOL/1000000.
       IF(DIST.EQ.80.)ANBAR=22.3569+60.89946*SLVOL/1000000.
       IF(DIST.EQ.160.)ANBAR=40.44935+115.03387*SLVOL/1000000.
       IF(DIST.EQ.320.)ANBAR=80.92548+223.30163*SLVOL/1000000.
       PRINT 117
117    FORMAT(* THE HOURLY TUG BILLING RATE IS    *)
       READ*,TUGPR
       PRINT 265
       BARGE=BARGE+(TUGPR-188.62)*ANBAR
```

```
      BARLO=BARGE◆.8
      BARHI=BARGE◆1.2
      RAILO=RAIL◆.8
      RAIHI=RAIL◆1.2
      TRULO=TRUCK◆.8
      TRUHI=TRUCK◆1.2
      PIPLO=PIPE◆.8
      PIPHI=PIPE◆1.2
      BARLD=BARLO/DSVOL
      BARGD=BARGE/DSVOL
      BARHD=BARHI/DSVOL
      RAID=RAIL/DSVOL
      RAILD=RAILO/DSVOL
      RAIHD=RAIHI/DSVOL
      TRULD=TRULO/DSVOL
      TRUCD=TRUCK/DSVOL
      TRUHD=TRUHI/DSVOL
      PIPLD=PIPLO/DSVOL
      PIPED=PIPE/DSVOL
      PIPHD=PIPHI/DSVOL
      PRINT 105
105   FORMAT(14X,◆BARGE◆,12X,◆RAIL◆,12X,◆PIPE◆,12X,◆TRUCK◆)
      PRINT 110,BARLO,RAILO,PIPLO,TRULO
110   FORMAT(◆ LOW◆,5X,F12.2,4X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 111,BARGE,RAIL,PIPE,TRUCK
111   FORMAT(◆ MEDIUM◆,2X,F12.2,4X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 112,BARHI,RAIHI,PIPHI,TRUHI
112   FORMAT(◆ HIGH◆,4X,F12.2,4X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 113
113   FORMAT (◆ COST PER DRY TON◆)
      PRINT 110,BARLD,RAILD,PIPLD,TRULD
      PRINT 111,BARGD,RAID,PIPED,TRUCD
      PRINT 112,BARHD,RAIHD,PIPHD,TRUHD
      PRINT 265
      PRINT 118
118   FORMAT (◆ END OF TRANSPORTATION TESTING (1=Y,2=N)?    ◆)
      READ ◆,ITEST
      PRINT 265
      IF (ITEST.EQ.2) GO TO 120
390   PRINT 195
195   FORMAT (◆ THE LOADING RATE (DT/A) IS    ◆)
      READ ◆,XLOAD
      ACRES=DSVOL/XLOAD
      PRINT 265
      PRINT 210
210   FORMAT (◆ SPRAY IRRIGATION COST TESTING◆)
      PRINT 265
      IHOLES=(ACRES/32.)+1
280   PRINT 225
225   FORMAT (◆ THE BULLDOZER HOURLY RENTAL IS    ◆)
      READ ◆,BULLPR
      STORAG=IHOLES◆BULLPR◆3
      DYPUMP=SLVOL/41400
      NPUMP=(DYPUMP/250.)+1
      PRINT 230
230   FORMAT (◆ THE PRICES OF PUMP, PIPE (PER FOOT), AND GUN ARE    •
      READ ◆,CPUMP,CPIPE,CGUN
      PRINT 240
240   FORMAT (◆ THE EXPECTED LIFE OF IRRIGATION UNIT IS    ◆)
      READ ◆,LSPRAY
      PRINT 235
```

```
235   FORMAT (◆ THE PRICE OF GAS IS    ◆)
      READ ◆,CGAS
      PRINT 245
245   FORMAT (◆ THE HOURLY APPLICATION WAGE IS    ◆)
      READ ◆,CWAGE
      PRINT 246
 246  FORMAT (◆THE AMORTIZATION RATE IS ◆)
      READ ◆, INT
      COSTEQ=((CPUMP+CPIPE◆600+CGUN)◆NPUMP◆INT◆(1+INT)◆◆LSPRAY)/
     + ((1+INT)◆◆LSPRAY-1)
      APCOST=((CPUMP+600.◆CPIPE+CGUN)◆NPUMP/LSPRAY)◆0.5+STORAG+COSTEQ
      APOPER=(DYPUMP◆3.333◆CGAS)+(DYPUMP/2.◆CWAGE◆8.)
      CAPPL=APCOST+APOPER
      DAPPL=CAPPL/DSVOL
      PRINT 265
      CAPPLO=.8◆CAPPL
      CAPPHI=1.2◆CAPPL
      DAPPLO=.8◆DAPPL
      DAPPHI=1.2◆DAPPL
      PRINT 290
290   FORMAT (40X,◆LOW◆,7X,◆MEDIUM◆,7X,◆HIGH◆)
      PRINT 255,CAPPLO,CAPPL,CAPPHI
255   FORMAT (◆ THE ANNUAL COST OF APPLICATION IS  ◆,F10.2,2X,F10.2
     +,2X,F10.2)
      PRINT 260,DAPPLO,DAPPL,DAPPHI
260   FORMAT (◆ THE ANNUAL COST PER DRY TON IS◆,9X,F6.2,6X,F6.2,6X,F6.2)
      PRINT 265
265   FORMAT (◆     ◆)
      PRINT 270
270   FORMAT (◆ END OF IRRIGATION TESTING (1=Y,2=N)?    ◆)
      READ ◆,JTEST
      IF (JTEST.EQ.2) GO TO 280
      PRINT 265
      PRINT 300
300   FORMAT (◆ HIGH FLOTATION SURFACE AND SUBSOIL APPLICATION TESTING◆)
      PRINT 265
      IHOLES=(ACRES/162.)+1
363   PRINT 305
305   FORMAT(◆ THE BULLDOZER HOURLY RENTAL IS    ◆)
      READ◆,BULLPR
      STORAG=IHOLES◆BULLPR◆3
      SPREDA=SLVOL/60000.
      SPREAD=SPREDA/250.
      NSPRED=INT(SPREAD)
      PRINT 310
310   FORMAT(◆ THE HFA OPERATOR'S HOURLY WAGE IS    ◆)
      READ◆,WAGE
      PRINT 315
315   FORMAT(◆THE PRICE OF DIESEL FUEL IS ◆)
      READ ◆,DIESEL
      PRINT 316
316   FORMAT(◆THE AMORTIZATION RATE IS ◆)
      READ ◆,INT
      PRINT 317
317   FORMAT(◆EQUIPMENT COSTS FOR HIGH-FLOTATION AND INJECTION ARE ◆)
      READ ◆,CHFA,CSUB
      IF(NSPRED.EQ.0) GO TO 330
      EXTRA=((SPREAD-NSPRED)◆60000./NSPRED)/7500.
      IF(EXTRA-2) 318,318,319
318   N=20000/(250◆(8+EXTRA))
      EQCOST=(CHFA◆INT◆(1+INT)◆◆N)/((1+INT)◆◆N-1)
```

```
     APCOST=((WAGE*8+WAGE*1.5*EXTRA+(1.10+DIESEL*6)*(8+EXTRA))*250+
    + EQCOST)*NSPRED+STORAG
     CEQSUB=(CSUB+INT*(1+INT)**N)/((1+INT)**N-1)
     SUBCOS=((WAGE*8+WAGE*1.5*EXTRA+(1.10+DIESEL*6)*(8+EXTRA))*250+
    +CEQSUB)*NSPRED+STORAG
     GO TO 340
319  NSPRED=NSPRED+1
     EXTRA=0
     N=20000/(8*(SPREDA/NSPRED)
     EQCOST=(CHFA*INT*(INT+1)**N)/((1+INT)**N-1)
     CEQSUB=(CSUB*INT*(1+INT)**N)/((1+INT)**N-1)
     APCOST=(WAGE+DIESEL*6+1.10)*8*SPREDA+STORAG+EQCOST*NSPRED
     SUBCOS=(WAGE+DIESEL*6+1.10)*8*SPREDA+STORAG+CEQSUB*NSPRED
     GO TO 340
330  N=20000/(8*SPREDA)
     IF(N-30) 331,331,332
332  N=30
331  COSTE=(CHFA*INT*(1+INT)**N)/((1+INT)**N-1)
     COSUB=(CSUB*INT*(1+INT)**N)/((1+INT)**N-1)
     APCOST=(WAGE+1.10+DIESEL*6)*8*SPREDA+STORAG+COSTE
     SUBCOS=(WAGE+1.10+DIESEL*6)*8*SPREDA+STORAG+COSUB
340  PRINT 265
     APCLOW=.8*APCOST
     APCHI=1.2*APCOST
     DAPCO=APCOST/DSVOL
     DAPLOW=.8*DAPCO
     DAPHI=1.2*DAPCO
     PRINT 345
345  FORMAT(41X,*LOW*,7X,*MEDIUM*,7X,*HIGH*)
     PRINT 350,APCLOW,APCOST,APCHI
350  FORMAT(* THE ANNUAL COST OF HF APPLICATION  *,F10.2,2X,F10.2,
    + 2X,F10.2)
     PRINT 355,DAPLOW,DAPCO,DAPHI
355  FORMAT(* THE ANNUAL COST PER DRY TON IS*,9X,F6.2,6X,F6.2,6X,
    + F6.2)
     PRINT 265
     SUBLOW=.8*SUBCOS
     SUBHI=1.2*SUBCOS
     DSUB=SUBCOS/DSVOL
     DSUBLO=.8*DSUB
     DSUBHI=1.2*DSUB
     PRINT 360,SUBLOW,SUBCOS,SUBHI
360  FORMAT (* THE ANNUAL COST OF INJECTING IS*,4X,F10.2,2X,F10.2
    +,2X,F10.2)
     PRINT 365,DSUBLO,DSUB,DSUBHI
365  FORMAT(* THE ANNUAL COST PER DRY TON IS*,9X,F6.2,6X,F6.2,6X,F6.2)
     PRINT 265
     PRINT 370
370  FORMAT(* END OF HFA AND INJECTION TESTING(1=Y,2=N)?    *)
     READ*,KTEST
     IF(KTEST.EQ.2)GO TO 363
379  PRINT 265
     PRINT 375
375  FORMAT (* THE COST OF LAND PER ACRE IS    *)
     READ*,ACREPR
     CACRE=ACREPR*ACRES
     PRINT 265
     PRINT 376,CACRE
376  FORMAT (* THE ANNUAL COST OF LAND IS*,4X,F10.2)
     DCACRE=CACRE/DSVOL
     PRINT 377,DCACRE
```

```
377     FORMAT(◆ THE COST OF LAND PER DRY TON IS◆,3X,F6.2)
        PRINT 265
        PRINT 378
378     FORMAT (◆ END OF LAND COST TESTING (1=Y,2=N)?    ◆)
        READ ◆,KTES
        IF (KTES.EQ.2) GO TO 379
        PRINT 265
        PRINT 380
380     FORMAT (◆ TEST OTHER LOADING RATES (1=Y,2=N)?    ◆)
        READ◆,LTEST
        IF(LTEST.EQ.1)GO TO 390
        DSLUDG=DSVOL
        GO TO 400
15      PRINT 600
600     FORMAT(◆ DEWATERED SLUDGE TRANSPORTATION TESTING◆)
        PRINT 265
        PRINT 605
605     FORMAT (◆ SLUDGE VOLUME IN CUBIC YARDS PER YEAR IS    ◆)
        READ◆,SLCUBE
        DSCUBE=55◆27◆SLCUBE◆.25/2000.
735     PRINT 610
610     FORMAT (◆ THE AVERAGE ONE-WAY HAUL IN MILES IS    ◆)
        READ◆,HAUL
        PRINT 620
620     FORMAT (◆ ARE LOADING FACILITIES AVAILABLE (1=Y,2=N)?    ◆)
        READ◆,JFAC
        IF(JFAC.EQ.1)GO TO 625
        IF(HAUL.NE.5.)GO TO 630
        IF(SLCUBE.LE.10000.)TRUCK=(12.63161+.48379◆SLCUBE/1000.)◆1000.
        IF(SLCUBE.GT.10000.)TRUCK=(6.45206+.82653◆SLCUBE/1000.)◆1000.
        GO TO 635
630     IF (HAUL.NE.10) GO TO 640
        IF (SLCUBE.LE.6000)TRUCK=(14.68954+.61206◆SLCUBE/1000.)◆1000.
        IF (SLCUBE.GT.6000)TRUCK=(9.23092+1.30539◆SLCUBE/1000.)◆1000.
        GO TO 635
640     IF (HAUL.NE.20) GO TO 645
        IF(SLCUBE.LE.5000)TRUCK=(15.2404+.97393◆SLCUBE/1000.)◆1000.
        IF (SLCUBE.GT.5000)TRUCK =(7.49239+2.47054◆SLCUBE/1000.)◆1000.
        RAIL=(3.02372+1.91831◆SLCUBE/1000.)◆1000.
        GO TO 635
645     IF (HAUL.NE.40) GO TO 650
        IF (SLCUBE.LE.4000)  TRUCK =(15.70964+1.83169◆SLCUBE/1000.)◆1000.
        IF (SLCUBE.GT.4000)  TRUCK =(9.89153+3.76113◆SLCUBE/1000.)◆1000.
        RAIL =(1.01718+2.63513◆SLCUBE/1000.)◆1000.
        GO TO 635
650     IF(HAUL.NE.80) GO TO 655
        TRUCK =(4.2407+8.01107◆SLCUBE/1000.)◆1000.
        RAIL =(-7.15147+4.06029◆SLCUBE/1000.)◆1000.
        GO TO 635
655     IF(HAUL.EQ.160)RAIL=(7.5738+5.96324◆SLCUBE/1000.)◆1000.
        IF (HAUL.EQ.320)RAIL=(16.46988+10.87881◆SLCUBE/1000.)◆1000.
        GO TO 635
625     IF (HAUL.NE.5)GO TO 660
        IF (SLCUBE.LE.10000)TRUCK=(28.96859+2.00845◆SLCUBE/1000.)◆1000.
        IF(SLCUBE.GT.10000)TRUCK=(32.80663+1.33876◆SLCUBE/1000.)◆1000.
        GO TO 635
660     IF (HAUL.NE.10) GO TO 665
        IF (SLCUBE.LE.10000)TRUCK=(27.81491+3.06032◆SLCUBE/1000.)◆1000.
        IF(SLCUBE.GT.10000)TRUCK=(45.9456+1.82099◆SLCUBE/1000.)◆1000.
        GO TO 635
665     IF(HAUL.NE.20) GO TO 670
```

```
      IF (SLCUBE.LE.10000)TRUCK=(30.49609+3.65198*SLCUBE/1000.)*1000.
      IF (SLCUBE.GT.10000)TRUCK=(48.88351+2.68121*SLCUBE/1000.)*1000.
      IF (SLCUBE.LE.70000)RAIL=(48.35354+2.3835*SLCUBE/1000.)*1000.
      IF (SLCUBE.GT.70000)RAIL=(88.54762+1.86542*SLCUBE/1000.)*1000.
      GO TO 635
670   IF (HAUL.NE.40) GO TO 675
      IF (SLCUBE.LE.10000)TRUCK=(32.77943+4.99852*SLCUBE/1000.)*1000.
      IF (SLCUBE.GT.10000)TRUCK=(42.43644+4.4421*SLCUBE/1000.)*1000.
      RAIL=(87.60572+2.7264*SLCUBE/1000.)*1000.
      GO TO 635
675   IF (HAUL.NE.80) GO TO 680
      IF (SLCUBE.LE.10000)TRUCK=(33.10586+7.42638*SLCUBE/1000.)*1000.
      IF (SLCUBE.GT.10000)TRUCK=(13.71023+8.19276*SLCUBE/1000.)*1000.
      IF (SLCUBE.LE.70000)RAIL=(56.6767+4.296*SLCUBE/1000.)*1000.
      IF (SLCUBE.GT.70000)RAIL=(90.84225+3.81997*SLCUBE/1000.)*1000.
      GO TO 635
680   IF (HAUL.EQ.160)RAIL=(112.50484+5.64791*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.320)RAIL=(120.89134+10.87728*SLCUBE/1000.)*1000.
635   IF (HAUL.LT.20)RAIL=0
      IF (HAUL.GT.80)TRUCK=0
      RALOW=.8*RAIL
      RAHI=1.2*RAIL
      IF (HAUL.EQ.5)TRFUEL=(-.04366+.14816*SLCUBE/1000.)*1000.
      IF(HAUL.EQ.10)TRFUEL=(.03033+.29593*SLCUBE/1000.)*1000.
      IF(HAUL.EQ.20)TRFUEL=(.049+.38038*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.40)TRFUEL=(-.07517+.76242*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.80)TRFUEL=(.05927+1.52372*SLCUBE/1000.)*1000.
      PRINT 690
690   FORMAT (* THE PRICE OF TRUCK FUEL IS    *)
      READ *,FUELPR
      FPR=(FUELPR-.73)*TRFUEL
      PRINT 695
695   FORMAT (* THE HOURLY WAGE FOR TRUCKING LABOR IS    *)
      READ *,WAGEPR
      IF (HAUL.EQ.5)TRHOUR=(-.01361+.08473*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.10)TRHOUR=(.0159+.11386*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.20)TRHOUR=(-.0159+.08614*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.40)TRHOUR=(-.01561+.12812*SLCUBE/1000.)*1000.
      IF (HAUL.EQ.80)TRHOUR=(.01238+.21191*SLCUBE/1000.)*1000.
      TRLAB=(WAGEPR-9.79)*TRHOUR
      TRUCK=TRUCK+FPR+TRLAB
      TRLOW=.8*TRUCK
      TRHI=1.2*TRUCK
      TRLOWD=TRLOW/DSCUBE
      TRUCKD=TRUCK/DSCUBE
      TRHID=TRHI/DSCUBE
      RALOW=.8*RAIL
      RAHI=1.2*RAIL
      RALOD=RALOW/DSCUBE
      RAILD=RAIL/DSCUBE
      RAHID=RAHI/DSCUBE
      PRINT 265
      PRINT 700
700   FORMAT (18X,*LOW*,11X,*MEDIUM*,11X,*HIGH*)
      PRINT 705,RALOW,RAIL,RAHI
705   FORMAT (* RAIL*,7X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 710,TRLOW,TRUCK,TRHI
710   FORMAT (* TRUCK*,6X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 715
715   FORMAT (* COST PER DRY TON*)
      PRINT 720,RALOD,RAILD,RAHID
720   FORMAT (* RAIL*,7X,F12.2,4X,F12.2,4X,F12.2)
```

```
      PRINT 725,TRLOWD,TRUCKD,TRHID
725   FORMAT (◆ TRUCK◆,6X,F12.2,4X,F12.2,4X,F12.2)
      PRINT 265
      PRINT 730
730   FORMAT (◆ END OF TRANSPORTATION TESTING (1=Y,2=N)?    ◆)
      READ◆,MTEST
      IF(MTEST.EQ.2)GO TO 735
      PRINT 265
      PRINT 740
740   FORMAT(◆ DEWATERED SLUDGE APPLICATION TESTING◆)
      PRINT 265
      SPDAYS=SLCUBE/288.
      GSPRED=SPDAYS/250.
      ISPRED=INT(GSPRED)
795   PRINT 750
750   FORMAT (◆ THE OPERATOR'S HOURLY WAGE IS    ◆)
      READ◆,ZWAGE
      PRINT 755
755   FORMAT (◆ THE PRICE OF DIESEL FUEL IS    ◆)
      READ◆,ZGAS
      PRINT 758
758   FORMAT (◆THE AMORTIZATION RATE IS ◆)
      READ ◆,INT
      PRINT 759
759   FORMAT (◆THE COSTS FOR SPEADERS AND LOADERS ARE ◆)
      READ ◆,CSPR,CLDR
      IF(ISPRED.EQ.0)GO TO 760
      EXTRA=((GSPRED-ISPRED)◆288./ISPRED)/36.
      FELOAD=GSPRED/4.
      ILOADR=INT(FELOAD)
      ZLOADR=FELOAD-ILOADR
      IF(ZLOADR.GE..25)ILOADR=ILOADR+1
      IF(EXTRA.GT.2)ISPRED=ISPRED+1
      NSPR=20000/(8◆(SPDAYS/ISPRED))
      NLDR=10000/(2◆(SPDAYS/ISPRED))
      EXCOST=((CSPR◆INT◆(1+INT)◆◆NSPR)/((1+INT)◆◆NSPR-1))◆ISPRED
      EQCOST=((CLDR◆INT◆(1+INT)◆◆NLDR)/((1+INT)◆◆NLDR-1))◆ILOADR
      ACOST=EXCOST+EQCOST+((ZWAGE◆8+ZWAGE◆1.5◆EXTRA)◆(ILOADR+
     + ISPRED)+((ZGAS◆6◆ISPRED+1.1◆ISPRED+ZGAS◆4◆ILOADR+1.1◆
     + ILOADR◆ISPRED/(ILOADR◆4))◆(8+EXTRA)◆(SPDAYS/ISPRED))
      GO TO 770
760   ISPRED=1
      ILOADR=1
      NSPR=20000/(8◆SPDAYS)
      NLDR=10000/(2◆SPDAYS)
      IF(NSPR.GT.30) NSPR=30
      IF(NLDR.GT.30) NLDR=30
      EXCOST=(CSPR◆INT◆(1+INT)◆◆NSPR)/((1+INT)◆◆NSPR-1)
      EQCOST=(CLDR◆INT◆(1+INT)◆◆NLDR)/((1+INT)◆◆NLDR-1)
      ACOST=EXCOST+EQCOST+((ZWAGE◆2+ZGAS◆6+ZGAS◆4+1.1+(1.1/4))◆
     + 8◆SPDAYS)
770   ACLOW=.8◆ACOST
      ACHI=1.2◆ACOST
      DACOST=ACOST/DSCUBE
      DACLOW=DACOST◆.8
      DACHI=1.2◆DACOST
      PRINT 265
      PRINT 775
775   FORMAT(35X,◆LOW◆,7X,◆MEDIUM◆,7X,◆HIGH◆)
      PRINT 780,ACLOW,ACOST,ACHI
780   FORMAT(◆ THE ANN.COST OF DRY APP. IS◆,2X,F10.2,2X,F10.2,2X,F10.2
```

```
      PRINT 785,DACLOW,DACOST,DACHI
785   FORMAT(◆ THE ANN.COST PER DRY TON IS◆,6X,F6.2,6X,F6.2,6X,F6.2)
      PRINT 265
      PRINT 790
790   FORMAT (◆ END OF DRY APPLICATION TESTING (1=Y,2=N)?    ◆)
      READ ◆,NTEST
      PRINT 265
      IF(NTEST.EQ.2)GO TO 795
825   PRINT 800
800   FORMAT (◆ THE LOADING RATE (DT/A) IS    ◆)
      READ◆,YLOAD
YOUR CONNECT TIME EXPIRES IN 5 MINUTES
      PRINT 265
      PRINT 805
805   FORMAT (◆ THE COST OF LAND PER ACRE IS    ◆)
      READ◆,CLAND
      ACRES=DSCUBE/YLOAD
      COACRE=CLAND◆ACRES
      DCACRE=COACRE/DSCUBE
      PRINT 810,COACRE
810   FORMAT (◆ THE ANNUAL COST OF LAND IS◆,4X,F10.2)
      PRINT 815,DCACRE
815   FORMAT (◆ THE COST OF LAND PER DRY TON IS◆,3X,F6.2)
      PRINT 265
      PRINT 820
820   FORMAT (◆ TEST OTHER LOADING RATES (1=Y,2=N)?    ◆)
      READ◆,ITES
      PRINT 265
      IF(ITES.EQ.1)GO TO 825
      DSLUDG=DSCUBE
400   PRINT 265
      PRINT 405
405   FORMAT(◆ MONITORING COST TESTING◆)
490   PRINT 265
      PRINT 410
410   FORMAT (◆ THE NUMBER OF MONITORING WELLS IS    ◆)
      READ◆,MWELL
      PRINT 420
420   FORMAT (◆ THE AVERAGE WELL DEPTH IN FEET IS    ◆)
      READ◆,DEPTH
      PRINT 430
430   FORMAT (◆ THE WELL DRILLING COST PER FOOT IS    ◆)
      READ◆,CPF
      WCOST=MWELL◆DEPTH◆CPF
      PRINT 440
440   FORMAT (◆ THE PER-TEST GROUNDWATER TESTING COST IS    ◆)
      READ◆,GWTC
      PRINT 445
445   FORMAT (◆ THE NUMBER OF TESTS NEEDED PER YEAR IS    ◆)
      READ◆,NUMBER
      TCOST=MWELL◆GWTC◆NUMBER
      PRINT 450
450   FORMAT (◆ THE MONITORING TECHNICIAN WAGE IS    ◆)
      READ◆,TWAGE
      TECH=TWAGE◆((MWELL/4)+2)
      TOTAL=WCOST+TCOST+TECH
      DTOTAL=TOTAL/DSLUDG
      PRINT 265
      PRINT 460,TOTAL
460   FORMAT(◆ THE ANNUAL MONITORING COST IS    ◆,F10.2)
      PRINT 470,DTOTAL
```

```
5530=470   FORMAT(* MONITORING COST PER DRY TON IS*,6X,F6.2)
5540=      PRINT 265
5550=      PRINT 480
5560=480   FORMAT (* END MONITORING COST TESTING (1=Y,2=N)?    *)
5570=      READ*,MON
5580=      IF(MON.EQ.2)GO TO 490
5590=      END
OK-SAVE,XYZ,NS.
OK-PURGE,X.
 PURGE,X.
OK-CATALOG,XYZ,SLUDG,RP=40.
YOUR CONNECT TIME EXPIRES IN 2 MINUTES
 CATALOG,XYZ,SLUDG,RP=40.
OK-LOGOUT,T.

JOB COST:  $      2.03
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APPENDIX D

SITE SPECIFIC FACTORS AFFECTING DISPOSAL COSTS

Site Modification

Access

Any type of application depends on access. In almost any situation, the final form of conveyance used to transport sludge to the forest site will be trucks. Rail, pipeline, or barges may be used to transport the sludge to a central distribution point, particularly if the application site is far from the point of sludge production. But none of the other means of transportation is as suitable as truck transport for short-distance haul to the various, changing locations which would be needed at the low sludge loading rates assumed here. Roads are, after all, far more ubiquitous than suitable watercourses, pipelines, or tracks.

While the existing road network offers some flexibility, forest roads are often more scarce than roads in general. And forest roads of a quality sufficient to handle diesel tank or dump trucks are in some places, scarcer still. The one advantage to forestland application, however, is that logging roads can be used, such that any place with recent or well-kept logging roads may have good enough access. Spur roads may need to be built, however, to provide access for even distribution of sludge on some sites. Since the road type and mileage required is probably site-specific, road construction costs were not in SLUDGE. Table D-1 shows Forest Service road construction-reconstruction costs experienced in 1977-78 (USDA, 1979). Since these roads are forest roads, and since roads suitable for logging trucks should be adequate for tank or dump trucks, these costs may be used as a rough guide to the kind of roading costs which can be expected if additional access roads are to be built for sludge application. Road construction is not cheap, and can add appreciably to application cost.

Table D-1. Forest Road Construction Costs: USDA Forest Service Timber Sale Summary Information, 1977-78.

Region[1/]	Road Type			Total Miles	Cost/Mile (Average)
	Constructed	Reconstructed	Temporary		
		(percent)			
1	36	37	27	1941.4	14,746
2	58	31	11	834.5	9,104
3	19	48	33	997.0	6,050
4	19	37	44	1012.3	5,198
5	14	61	25	2732.2	13,426
6	24	47	30	5007.9	19,126
8	15	18	67	2517.7	5,329
9	25	22	53	180.2	7,185
10	57	17	26	73.6	71,520[2/]

[1/] U.S.D.A. Forest Service regional data were used.

[2/] Region 10 (Alaska) road costs are unusually high in comparison for a number of reasons. These include such things as the fact that nearly all Forest Service land in Alaska is coastal: i.e. steep, rocky, fragile terrain; much of the land is on islands, so road building equipment must be shipped to the sites; and the generally high cost of everything in Alaska.

Site Preparation

Like road construction, site preparation may be unnecessary. Spray irrigation can be used on sites with some existing vegetation, though the existence of dense understories precludes application. The vehicular applications, however, require fairly clean sites, either clearcuts or plantations with adequate spacing between rows. Subsoil injectors, moreover, require a root-free zone of at least 6" depth.

Site preparation, then, may be necessary to permit the use of some equipment required for dispersal of sludge. Methods of site preparation vary widely by the amount of material to be cleared, method of clearing, terrain, and so forth. Burning may cost less than $5 per acre, or as much as $80/acre; root plowing generally costs about $75 per acre, and roller chopping approximately $55 per acre. There are other methods of site preparation, but mechanical means and fire are usually the most efficient means of removing unwanted vegetation per dollar of expenditure.

Since site preparation is commonly employed after a stand of timber is harvested in order to help insure adequate reforestation, the landowner or timber purchaser often bears site preparation costs. Since SLUDGE was written primarily for the waste manager seeking only a way to dispose of sludge, site preparation was not included. If a particular agency is interested in beneficial reuse of sludge as well as disposal, and wishes to invest in timber management as well as sludge recycling, many factors other than site preparation must be considered. That is beyond the scope of this study.

Retreatment

One of the pivotal factors in the cost of forest land application of sludge is retreatment. If areas can be retreated, the application costs may be significantly lowered. SLUDGE assumes new, single-time application, but retreatment may be feasible in some instances. If areas are retreated, temporary storage pits may be re-used rather than new ones dug each cycle, or permanent field storage can be built. Existing monitoring wells can be utilized, eliminating nearly all monitoring costs. Solid-set irrigation can be used, rather than the moveable spray irrigation equipment assumed in SLUDGE.[1/]

There are also several intangible factors which may tend to reduce costs if retreatment can be used. In general, they have to do with familiarity, or learning. As the waste management agency becomes more familiar with each site, it will become clear how high the loading rates can be without adversely affecting groundwater. Hence, fewer groundwater tests may be used. It may be that a yearly or seasonal application pattern can be developed, freeing equipment or personnel during periods of historically inclement weather or periods when there is not enough sludge to apply, as in the case of a small municipality whose entire annual sludge production can be applied in a matter of weeks. If such a pattern is feasible, other seasonal or cyclical uses can be found for personnel and equipment, and their costs charged to other activities. As shown in the chapter on model validation,

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[1/] Young (1978) indicates that center-pivot irrigation of waste-water is slightly less expensive than solid-set, but that solid-set irrigation is more versatile with respect to the treatable terrain than is center-pivot.

if all application equipment and personnel costs are attributed to sludge disposal, the per-dry-ton disposal costs for small-to-medium-sized waste producers can be overwhelming.

There is nothing in present regulations which prohibits retreatment of land which is not used for the production of food chain crops. Sludge may legally be reapplied any number of times, as long as it does not exceed the groundwater quality criteria published in the Federal Register in September of 1979 (40 CFR 257, 1979) and reproduced in Appendix A. Exactly how many times a site can be re-entered is not known, and depends on many factors whose role is not completely clear at present. It would be difficult to predict how often a site could be treated even if the sludge composition, ecotype, soil characteristics, plant uptake rates climate, and loading rates were known, as the eventual fate of many pathogens and micronutrients or heavy metals in the environment is simply not known. Hence, retreatment is not specifically included in SLUDGE, though not excluded per se. To get an idea of reduced costs if retreatment were feasible, groundwater monitoring well-drilling and field storage could be eliminated after the first application.

Construction Grants

SLUDGE begins essentially at the wastewater treatment plant site, and does not attempt to portray any costs other than those of transportation, land application, and monitoring of sludges. Other costs for waste treatment are not included, but in practice the decisions regarding treatment and disposal must be made jointly. One factor which may make land application (particularly forestland application) more attractive is the Construction Grants program, designed to promote, through increased federal grants for waste treatment, what EPA calls Innovative/Alternative (A/I) Technology. This is any waste treatment technique which, in general, provides for recycling or beneficial reuse of resources in waste, while reducing costs and/or energy requirements (EPA, 1980a). Significantly, both silvicultural use of effluent and land application of sludge are specifically identified as I/A technologies, and facilities opting for this type of disposal are eligible to receive 85 percent federal funding for wastewater treatment works (as compared to 75 percent for non-I/A solutions). Moreover, if the technology fails to meet design goals during the first two years of operation, another grant may be awarded for 100 percent of the costs of correcting the failed system, or replacing it with another, hopefully better, system.

APPENDIX E

REVIEW OF HEALTH AND NUISANCE HAZARDS

Nuisance

The primary nuisance-causing attribute of sludge is malodorous emissions, which ranked first in public opinion surveys designed to identify air pollutants of concern (Osag and Crane, 1974). Though there is no specific relationship between odor and any threat to health such as disease or toxicity, odors can cause allergic reactions, poor appetites, lower water consumption, impaired respiration, vomiting, nausea, insomnia, and stress (Mosier, et. al., 1977).

There is usually little guidance in existing regulations for dealing with odors. This is unsurprising, in view of the fact that there is no reliable, objective method of measuring odor. The usual descriptors of odor are subjective; most people can discern the difference between strong, medium, and weak odors and can describe the quality by association with familiar smells (Mosier, et. al., 1977). Both the intensity and the quality govern the type of reaction to any smell. Even objectionable odors may be acceptable at low intensities, while perfumes are obnoxious at high intensities.

There is no technologically and economically feasible way of preventing odors from occurring when large concentrated sources of organic wastes exist (Mosier, et. al., 1977). Some things can be done to ameliorate odors; in particular, incomplete anaerobic digestion seems to lead to the formation of particularly obnoxious odors, so complete digestion is one preventive measure that can be taken.

One of the most efficient ways of avoiding odor problems may be built into forest and noncropland waste application. Most forested and many noncropland areas are physically removed from concentrations of population, limiting the exposure to malodorous emissions. Where otherwise suitable disposal sites exist near areas of population concentration, it may be worthwhile to avoid using them for waste disposal, especially if the distance to other, more remote sites is not too great.

Health

Every generation defines safety differently. Indeed, every individual may have different standards for what is considered safe. During World War II, for example, one of the jungle soldiers' most effective weapons was DDT: not for use against human enemies, but against typhus, malaria, typhoid, and dysentery. Direct application to the skin was a common method of application. Even further back in history, drugstores commonly carried, as over-the-counter medicines, such things as tinctures of opium, laudanum, and paregoric (Lowrance, 1976). By today's standards, these things exceed the margin of safety our particular society is willing to live with; they are unsafe. But "safe" can only be defined in the context of today, and it is being redefined on a continuing basis. Therefore, it is impossible to say categorically whether or not land application of sludge is safe. The only true risks associated with non-cropland sludge application, within the limits on ground and surface-water pollution already discussed, are considered acceptable.

This, at least, is "society's" opinion, insofar as it is mirrored by the existing statutes and regulations. In its continuing efforts to implement the legislation designed to clean up the country, EPA published the following policy statement:

> ...land application of solid waste coupled with good management techniques for enhancement of parks and forests and reclamation of poor or damaged terrain is a desirable land management technique...In recognition of...public health concerns, the Agency prefers the application of solid waste to non-food-chain land... (40 CFR Part 257, 1979).

By referring to "public health concerns," EPA acknowledges that there are nasty things in sludge--things which, taken in improper form or dosage, could hurt people or other fauna beyond the point of acceptability. First, there are pathogens: viruses and bacteria capable of infecting people with diseases (Menzies, 1977). Ascaris llumbricoides, a round worm, can survive primary treatment and affect human health (again, assuming sufficient exposure takes place). The Entamoeba histolytica, which causes amoebic dysentery, may also survive for a few days in soil. There are others, waterborne bacterial diseases, which can contaminate people if water from treated sites finds its way into surface or irrigation waters used in some way for human consumption. Salmonella (typhoid and paratyphoid), Salmonella typhimurium (gastroenteritis), Shigella (bacillary dysentery), and Pseudomonas are present, and though infection usually requires fairly hefty exposure, such exposure is possible if land application is grossly mishandled.

In addition to pathogens, most municipal and industrial sludges contain trace amounts of heavy metals which, if ingested, can be linked to harmful or potentially harmful human effects. In most cases, the effects are unknown, or not proven beyond reasonable doubt, but in some cases, this very lack of information serves only to exacerbate health issues.

There is not way to account for every virus, every drop of water, every metal ion applied to a site in sludge. Further, there are some components (like viral hepatitis) which we are not able to detect using today's technology, but which may be present. Finally, there is a substantial lack of conclusive information on health effects of many constituents of sludge. Where information on risk does exist, it is often contradictory and confusing. For example, different studies on the health effects of cadmium have shown results from no health risk to clear and present danger. In short, there is no consensus of scientific opinion on the risks of land application of sludge. Therefore, not surprisingly, there is a great diversity of popular opinion on the safety of land application.

Though some decision makers and analysts tend to discount popular opinion, it can be a powerful force. Some scientists assure us, for example, that the record of land application (including agricultural land) is unblemished by epidemics, and that we have little to fear but fear itself:

> ...utilization of urban and animal wastes is probably impeded to a greater extent by the fear of disease than by the actual disease hazard involved. Information from field tests suggests that the hazards from pathogens are more imaginary than real. Irrigation of soil with liquid digested sludge is accepted in Great Britain, Germany, and France, where more than 100 years of practice in sewage-farm irrigation has produced no epidemics of cattle or animal disease. (CASE, 1975).

Others cite evidence of problems. An outbreak of cholera in Jerusalem was traced to application of sewage to vegetables. A similar cholera outbreak in the City of Gaza may be linked to sewage application. Other scientists, in Denmark, linked bovine tuberculosis with sewage irrigation of pastureland (Love, et. al., 1975). Where scientists do not agree, or present seemingly contradictory evidence, it is almost a matter of form that public opinion will mirror and usually amplify the inconsistencies and debate. In many cases, what facts exist are obscured, and major decisions are made on the strength and tenacity of the opinions of opposing groups.