SLUDGE MANAGEMENT DISPOSAL AND UTILIZATION

Proceedings of the
Third National Conference on
Sludge Management
Disposal and Utilization

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December 14–16, 1976

Miami Beach, Florida

Sponsored by:
Energy Research and Development Administration
U.S. Environmental Protection Agency
National Science Foundation
Information Transfer Inc.

Printed in the United States of America

Library of Congress Catalog No. 77-81964

Information Transfer Inc.
1160 Rockville Pike
Rockville, Maryland 20852

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EPA's Sludge Management Program: New Responsibilities and Challenges

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I am pleased to discuss a topic of mutual interest—the management of residual sludge—and, in particular, two events that will affect the shape of Environmental Protection Agency (EPA) policy and programming on the land disposition of sludge: the passage of the Resource Recovery and Conservation Act of 1976 (PL 94–580), and the creation of EPA's Residual Sludge Working Group.

From EPA's perspective, insuring environmentally acceptable sludge management is not only a responsibility, but also a challenge. As we move forward in our efforts to clean up the air and water, we generate increasing quantities of sludge. Utilizing and/or disposing of this sludge in a manner that does not significantly degrade the environment is clearly a major responsibility of this Agency. The new law, PL 94–580, helps us to define this responsibility better by clarifying our authority over the land disposition of sludge.

As the sludge disposal problem grows, both in size and in scope, the development of a unified and well coordinated EPA policy on sludge management becomes more critical. Developing such a policy, and coordinating the many diverse program activities that will support it, are definite challenges. EPA's Residual Sludge Working Group, composed of affected offices within the Agency with an interest in sludge management, is striving to meet these challenges by integrating all policy planning and guidance work across program and office lines.

Let me expand first on the new legislation and our sludge disposition responsibilities. PL 94–580 was signed into law on October 21, 1976. Called the Resource Recovery and Conservation Act of 1976, this law provides the Federal Government with the authority to protect health and the environment and facilitate resource recovery and conservation in the face of the growing solid waste disposal problem. Under the Act, a permit program is established to manage the disposition of potentially hazardous materials from their point of origin to their final disposition. The legislation also mandates state and regional solid waste plans aimed at phasing out open dumps. Through its Office of Solid Waste, the Environmental Protection Agency has the authority to provide technical and financial assistance to help states develop and implement solid waste, resource recovery and resource conservation plans and systems. In addition, the Act expands EPA's current research, development, and demonstration of solid waste management technologies.

How will this new piece of legislation affect sludge? We can begin to answer this question by looking at the definition section of the Act (Subtitle A, Section 1004). There are three definitions that are of importance to sludge management:

- *Solid waste* is defined as "any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility. . . "
- *Disposal* is defined as "the discharge, deposits, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwater."
- *Hazardous waste* is defined as a solid waste that may "pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed."

These definitions suggest that anything in the Act that refers to solid waste or solid waste management also refers to sludge and sludge management. Furthermore, the definition of disposal, which includes placing waste *in* or *on* any land, clearly encompasses both sludge utilization and sludge disposal in a landfill. The definition of hazardous waste also leaves open the possibility that some sludges, like some solid wastes, may be hazardous and may, therefore, be covered under the hazardous waste control program of PL 94–580 (Subtitle C).

Our preliminary analysis of the Act, then, suggests a major emphasis on residual sludge management. Specifically, we now envision the following:

- *Guidelines* (Section 1008)—We are required to write guidelines for solid waste management that will be mandatory for federal facilities and advisory for states. We plan to write guidelines for sludge utilization and disposal that would fall under this section. The guidelines will likely include descriptions of sludge management practices and performance levels. They will differ from the proposed technical bulletin that appeared in the Federal Register of June 3, 1976, in that the technical bulletin is intended to provide guidance on the disposal of sludge to the Regional Offices of the Environmental Protection Agency during the review of grant applications for the construction of wastewater treatment plants.
- *Technical Assistance* (Section 2003)—We are required to provide teams of personnel to assist states and localities with solid waste management problems, including sludge.
- *Hazardous Wastes* (Subtitle C)—We are required to define which solid wastes are hazardous, and to establish a permit program and write guidelines to enable the states to control hazardous wastes. To the extent that some sludges may be defined as hazardous wastes, this subtitle will affect sludge management.
- *Planning and Open Dumps* (Subtitle D)—We are required to approve and fund state solid waste plans and through this

mechanism prohibit open dumping of solid wastes. Residual sludge management may be included in such plans, perhaps by a permit program at the state level. We also believe that some current sludge disposal practices may fall under the definition of open dumps, and therefore be phased out within 5 years of the approval date of the state plan.

- *Public Participation* (Section 6004)—The legislation provides for public participation in the development and implementation of the Act. We are taking this language very seriously. We will be involving the public in every major step of the process through advisory groups, public meetings, and public information dissemination. Our first public meeting, scheduled for December 16, will be used to solicit public opinion on how the law should be implemented. Other similar meetings will be held as we move toward the development of programs and the promulgation of guidelines.

I realize that what I have just said may seem very broad and sweeping. It should, nevertheless, give some indication of what our present plans are vis-a-vis sludge utilization and disposal. From a philosophical point of view, we feel that beneficial uses of sludge are to be encouraged. However, while the use of such sludges on non-food chain crops can be generally applauded, the risks associated with the uptake of heavy metals and other toxic substances make it clear that they should not be applied to food chain crops without careful testing and evaluation of both the sludge and the solids to which it would be applied. Even if sludge is disposed of in a landfill, there is danger that the heavy metals will be leached into groundwater. We expect to be able to use the new legislation to control environmentally undesirable means of sludge disposal.

As you may imagine, the development of our programs under this new legislation will require extensive coordination with other offices of EPA that have an interest in sludge management, particularly the Office of Water Program Operations and the Office of Research and Development.

Let me begin this part of the discussion with a little history on the Residual Sludge Working Group. In January of 1976, John Quarles, Deputy Administrator of EPA, issued a memo giving the Office of Solid Waste the overall responsibility for "coordinating the development of Agency policy, planning and guidance in the area of the utilization and disposal of sludge." Our first action under this mandate was to form a Residual Sludge Working Group, composed of representatives of the many program offices within EPA that have an interest in the sludge issue. Membership in the group thus includes not only the Office of Solid Waste, but also the Office of Water Program Operations, the Office of Research and Development, the Office of Enforcement, the Office of Planning and Management, and last, but perhaps most important, a representative of EPA's regional offices.

Working Group activities center around four major tasks:

- Identification of technical, scientific and programmatic problems and issues,
- Coordination of on-going programs addressing those problems,
- Development and recommendation of future programs, and
- Development, coordination and recommendation of residual sludge management policy.

The first major activity of the Sludge Working Group was to prepare an Action Plan for Residual Sludge Management. This plan was designed to identify the constraints to Agency sludge management, and to propose particular action items for the resolutions of the problems identified. The plan was signed on October 19, 1976 by John Quarles, and work is now under way on the immediate action items prepared proposed in the plan.

Briefly, the plan identifies four major problem areas as barriers to implementation of an effective sludge program: (1) a lack of data on public health and environmental issues related to sludge utilization and disposal, as well as confusion over the interpretation of existing data; (2) problems associated with the technologies for sludge processing, treatment and disposal; (3) a lack of consistency in air, water and land use guidance with respect to sludge and its constituents; and (4) social, economic and institutional constraints. To resolve these issues, immediate and long-term action items are listed with completion dates where appropriate.

Within the next nine months, we hope to have the following items completed:

- An official clarification of the roles of EPA, USDA, and FDA with regard to sludge management.
- Issue papers that analyze (1) communication links between EPA and States, (2) the scope of existing legislative authorities for handling sludge, and (3) the contents of the planning reports produced under the construction grant program.
- Program plans that (1) integrate sludge management and EPA's water planning program, (2) enlarge the Technology Transfer Program to include the management of industrial sludge, (3) develop a comprehensive public awareness program, (4) develop an integrated program for industrial sludge management.
- A comprehensive strategy paper for municipal sludge management.
- EPA's Technical Bulletin on municipal sludge management.
- Interim standard methods for sampling sludge, soil, and crops.
- An environmental analysis that compares the disposal of sludge in the different media.

In the long-term, the Action Plan of the Residual Sludge Working Group has identified a number of detailed program areas that will require increased attention. They involve obtaining the data necessary to determine the impact on public health and the environment of various sludge utilization and disposal options, broadening the technological base for sludge utilization and disposal, and providing information to cities and industries on how to select an economical sludge utilization and disposal option. These projects will hopefully begin sometime in calendar year 1977.

Now that I've given you a bird's-eye view of the potential impact of the new solid waste legislation and the activities of the Residual Sludge Working Group on sludge management, I would like to assure you that all the on-going sludge work, in EPA, other Agencies, and the research community, will form the cornerstone of EPA's sludge policy and programs. If we are to manage sludge in an effective and environmentally sound manner, we must rely on and coordinate with those who have been actively working in the field over the past several years. Having the authority to handle a problem is only a part of the equation. Working cooperatively with all of those concerned will yield the only viable solution.

Impact of Sewage Treatment and Operations on Sludge Handling and Disposal

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INTRODUCTION

Waste treatment is normally based on the desire to eliminate objectionable qualities that are found in wastewater. This can be done in a number of different ways: 1. physically remove the constituents; 2. alter the physical state of impurities so that they can be removed (e.g., from a dissolved form to a precipitate); or 3. alter the chemical state to a less objectionable one, such as conversion of ammonia to nitrate. Most wastewater unit operations involve the first two removal modes. Therefore in treating wastewater, process residues are generated. These materials are often overlooked or not given sufficient attention in early stages of process development and system design. Many excellent papers are given in the conference on a variety of new sludge handling and disposal techniques. This paper focuses on the upstream end of waste treatment system design, the generation of sludge in relation to the design and operation of waste treatment facilities. It will touch on some of the controlling factors in sludge generation to serve as a basis for further, more in-depth, technical discussions. A major point of emphasis is that planning for sludge handling and disposal must start at the very beginning of process selection.

The major factors that influence quantity and characteristics of sludge are:

- Influent waste characteristics
- Degree of treatment required
- Unit processes selected
- Design of unit processes
- Operating mode.

These will be discussed separately in more detail. The impurities of primary concern in influent wastes are:

- Solids
- Dissolved organics (BOD/COD)
- Nutrients (nitrogen and phosphorus)
- Toxic substances (heavy metals, pesticides, organics)
- Microorganisms (bacteria, virus and others)
- Dissolved inorganics
- General quality characteristics (dissolved oxygen, temperature, pH, color, odor)

Influent Waste Characteristics

The first item on the list includes settleable, suspended and floating solids. Note that during many treatment processes, dissolved materials are converted to insoluble solids. Removal of dissolved organics is considered very important, particularly in relation to biodegradeable organics that exert BOD and COD. In addition, dissolved organics can impart a taste and odor to waters that might be used for water supply; they might also support unsightly growths in streams as well as have toxic or hazardous characteristics. Removal of nitrogen and phosphorus as nutrients are also of prime interest. Nitrogen in the ammonia form has additional objectionable characteristics. It is toxic to large numbers of aquatic organisms. It exerts a significant oxygen demand as well as a chlorine demand for water treatment operations. Nitrogen in the nitrate form has been implicated in methemoglobinmia, a condition that strikes infants in areas with high nitrate drinking water. The first three classes of impurities normally result in the greatest amounts of sludges during waste treatment operations.

Toxic substances must also be removed from wastewater; these include heavy metals, pesticides and others. Microorganisms, such as bacteria, virus, amoeba and other parasites exert, of course, a profound influence on public health. Dissolved inorganics might effect the aesthetic qualities of water, such as taste, or might prevent us from using water in ways that we want, such as agriculture. The removal of dissolved inorganics, aside from those listed above, has not been a priority concern; however, with the "no-discharge" goal of PL 92–500, the removal of dissolved inorganics will most likely play a much more important role in the future. In this case, process residues are likely to be concentrated inorganic brines as opposed to sludges. The difficulty in proper and safe disposal of these materials will equally match those associated with organic sludges.

Finally, there is a series of general characteristics that are important to be maintained at desired levels; these include dissolved oxygen, temperature, pH, color, and odor in order to maintain a high level of aquatic life, or to maintain an acceptable level of aesthetics. There are, of course, other impurities of concern; however, the above general list includes the majority of those of greatest interest.

As mentioned previously, the influent waste characteristics exert a profound influence on the quality and quantity of sludges generated. The following indicates the main influences on the characteristics of influent wastes:

- Industrial Contributions
- Infiltration/Inflow
- Stormwater Inclusion
- Garbage Grinders
- Length of Sewer System
- Water Supply Characteristics

The effects of industrial contributions to sludge quality and quantity are often direct. Settleable and floating solids discharged to a municipal sewer system will, for the most part, be removed in primary treatment and sent directly to the sludge disposal system. In addition, one must be aware that the generation characteristics of biological sludges are also significantly influenced by industrial contributions. Each of the organic compounds exhibits its own characteristics in terms of sludge production rates. For example, compound A could produce a higher amount of sludge per pound of BOD removed than compound B in a biological treatment system. Thus if a particular treatment system has a high percentage of organic industrial discharges, there is the possibility that sludge production could be significantly affected. Many organic compounds, for example, generate sludge at very low rates; in these cases, much less sludge may be produced than would be expected under pure domestic sewage conditions. Thus, when planning for sewage treatment systems that include a high level of industrial contributions, one must include sufficient laboratory tests on the actual sewage to determine the sludge generation characteristics. Industrial wastes also often contain materials which, while soluble in the sewage, are adsorbed by activated sludge during secondary treatment. When sludge is wasted, these adsorbed materials are then carried out in the waste sludge and must be considered in the design and operation of sludge treatment and disposal. Heavy metals, for example, fall into this category. Under most conditions, biological waste treatment plants are reasonably efficient in removing low levels of heavy metals; that is, levels below that which would inhibit or cause toxicity to the biological systems.

Infiltration/inflow will mainly affect the hydraulic characteristics of incoming waste. In addition, however, a higher level of grit, or inert material, may be included. This could have a significant detrimental effect on mechanical unit operations, particularly those dealing with sludge handling and treatment. The inclusion of urban stormwater runoff in municipal systems has a same general result in relation to sludge. In this case, additional materials such as road oils, lead, and other heavy metals might be included in the system.

If garbage grinders are allowed in the sewer system, one could expect a higher amount of suspended and settleable solids coming to the waste treatment facility, since the contributing population would tend to be discharging more solids into the sewer system. Because most of this material would be of food origin, one would expect a higher level of organic solids (volatile solids) in the resultant sludge.

The length of the sewer system could effect the septicity of the incoming waste; this could, in turn, change the condition of primary sludges as they are routed to the sludge handling and disposal systems. Some water supplies contain inorganic materials which are either altered or removed during treatment and thus find their way into the sludge. This mainly includes the hardness and alkalinity of incoming wastewater. If advanced waste treatment, including chemical precipitation unit operations, is practiced, the characteristics of the water supply can greatly influence the amount and characteristics of the resultant sludge.

Treatment Required

The major influence on the amount and quality of sludge generated is the type of treatment provided. This is, of course, a direct function of the degree of treatment required. Public Law 92–500 requires a whole variety of new types of unit operations to meet effluent and water quality requirements as spelled out by Congress. Included in this law is the concept of effluent quality versus water quality limited streams. The Act requires that all publicly-owned treatment works provide secondary treatment by 1977. At the same time, industrial discharges will be required to provide the "best practicable treatment" for their discharges. By 1983, industrial discharges will be required to provide a higher degree of treatment, "best available treatment". Both BAT and BPT are or will be defined by EPA. Effluent limited streams are those which can meet desired water quality goals with the base treatment levels as required in the Act. Those streams which cannot meet the desired water quality goal will require a higher level of treatment; these are known as water quality limited streams. For municipal systems, advanced waste treatment unit operations will probably be required for water quality limited streams. The tertiary or advanced unit operations will generate new and more difficult types of sludges.

Process residues from secondary biological treatment involve the removal of BOD, suspended solids, and bacteria. The residual sludges reflect the goal of treatment. When tertiary or advanced treatment are utilized, a higher level of removal of these same impurities is often the goal. However, other constituents may also be removed such as phosphorus, nitrogen, and in some cases, metals and refractory organics. The process residues from these unit operations could differ markedly from those associated with conventional secondary treatment.

There are a number of approaches that could be used to reach secondary treatment or its equivalent. The most widespread system in use today is the activated sludge treatment process. Typically, one could expect between 0.4 and 0.5 pounds of biological sludge to be generated for every pound of BOD removed. This is also true of trickling filtration which is a related biological treatment system. Independent physical-chemical treatment could also be used to provide equivalent secondary treatment. In this case, the unit operations do not rely at all on biological systems but on a series of physical treatment steps which include chemical precipitation. Typically, a PCT plant will include preliminary treatment (similar to biological treatment), a chemical precipitation step, usually carbon adsorption, and in many instances filtration. If required at the specific location, a unit operation to remove nitrogen as ammonia might also be included. At the present time there are few physical chemical treatment systems in operation; however, their numbers are increasing. A small treatment plant has been in operation at Rosemount, Minnesota for several years. The Rocky River, Ohio plant has been on stream for over a year. A very large plant in Niagara Falls is near startup; the Cleveland Westerly plant is well along in construction. A new plant in Fitchburg, Massachusetts has been in operation for over a year; it deals mainly with industrial waste with some municipal waste included. There are several other PCT plants that are under construction or have been designed. Obviously the major process residue of interest would be the chemical precipitation of sludge. PCT plants use either alum, ferric chloride or lime for this initial treatment step. In this sense, the PCT system resembles somewhat a primary treatment that uses chemical addition to improve organic solids removal or to remove phosphorus.

Land application of partially treated sewage does not represent any unusual problems in relation to sludge disposal. One can, under most conditions, assume that if the land application of sewage is acceptable, the land disposal of sludges that would be generated during the treatment of the sewage would similarly be acceptable, although at a different application rate.

Unit Processes Selected

There are a number of advanced or tertiary unit operations that could be employed in the treatment of secondary effluent to provide a higher quality of discharge. The basic types are

- Chemical precipitation/clarification
- Filtration/microstraining
- Ion exchange (NH_3)
- Break-point chlorination (NH_3)
- Air stripping (NH_3)
- Biological nitrification/denitrification
- Carbon adsorption

Chemical precipitation and clarification along with flocculation, is used primarily for the removal of phosphorus; however, the process also removes additional amounts of suspended solids and associated BOD. As with the PCT system, this can be accomplished with three types of chemicals: lime, alum, and iron salts. Alum and iron salts are used either in the primary stage (added just before primary treatment) with chemical sludge being removed along with primary sewage solids. It can also be added at the exit of the aeration basin of a secondary activated sludge plant. This is a particularly popular location for chemical addition where medium levels of phosphorus removal are required. Lime, on the other hand, is either added in the primary system or in a separate tertiary system. A high pH is required for effective lime treatment; this creates conditions which are unsuitable for most biological systems.

Filtration, of course, is the removal of additional suspended solids; as suspended solids are removed, additional associated BOD is also removed. Typically, about half of the BOD associated with conventional activated sludge plant effluent is in the form of suspended solids so that if a significant portion of suspended solids is removed by filtration, a corresponding amount of BOD will also be removed. The characteristics of the solids removed by filtration are almost identical to those that are released from the upstream unit operation. In most instances, a small amount of coagulant such as alum is added to provide some flocculation and enhance the removal process. In general, however, the filtered solids operating on secondary effluent will be almost identical to waste activated sludge; similarly, filtration solids operating on effluent from a separate stage lime phosphorus removal system will contain significant amounts of inorganic solids.

Air stripping is used for the removal of ammonia. The pH of the influent waste is raised to over 11 and air is blown through it to strip out the ammonia to the atmosphere. Some work has been done in regard to recovery of ammonia; however, at this point in time no full scale plants have been placed in operation. The recovery system involves adsorption of ammonia with acid solution and subsequent sale or use of the ammonium solution as fertilizer. A selective ion exchange unit operation has been successfully used to remove ammonia from wastewaters. The ion exchange zeolite operates in a packed bed and, therefore must be periodically backwashed to remove entrapped suspended solids. Therefore, it generates a small amount of filter-like waste solids. When the ion exchange capacity is exhausted, it must be regenerated. In this process, one ends up with a waste regenerate fluid which must be purified so that the regenerate can be reused. This can be accomplished by either breakpoint chlorination or air stripping. As was noted in the previous discussion, air stripping was accomplished at elevated pH. This causes a small amount of solids to be precipitated from the waste regenerant fluid. The amount is not particularly large, but must be considered in the design of residue disposal systems.

Biological nitrification-denitrification is another means of removal of nitrogen. The process configuration is similar in design to activated sludge systems. A popular variation of this process is to employ two separate stages after activated sludge. In the first stage, nitrification is accomplished in a suspended growth mode in the presence of sufficient aeration to both mix the biological solids and supply sufficient oxygen for the nitrifying bacteria. The bacteria responsible for nitrification are different from those associated with conventional activated sludge. Nitrifying bacteria are very slow growing; consequently, a basic problem is to maintain a sufficient bacterial population. In separate stage nitrification, therefore, a typically major concern is to have sufficient sludge. Therefore, the net sludge generated from nitrification is usually very small in volume if any at all. It is normally considered good practice to provide for the transfer of sludge from secondary treatment to a separate stage nitrification system so that sufficient solids can be maintained.

Denitrification can be carried out as a fixed film system, such as trickling filter, or in the suspended growth mode, such as conventional activated sludge. In the suspended growth mode, a low level of mixing is provided to maintain the biological solids in suspension. However, attempts are made to minimize the amount of oxygen transfer since the denitrification process must take place under anaerobic conditions. Similar to activated sludge, denitrification generates waste biological sludges that require disposal. Aside from the fact that the sludge is anaerobic, denitrification sludge is quite similar in character to that wasted from activated sludge plants. The volume of sludge per million gallons wasted is normally in between those values associated with conventional activated sludge and the low values associated with nitrification sludge.

Carbon adsorption, itself, does not generate any residue. Some plants are operated in a downflow, packed bed configuration; therefore, the beds must be backwashed to remove accumulated trapped solids. In the regeneration of spent activated carbon, some carbon fines are produced which are removed in a de-fining operation prior to reuse in carbon contact beds. The fines removed are small in volume and are usually simply mixed with the normal process residues streams. Typical dry sludge production rates for various major residue producers are:[2]

Primary	- 1,000 lb/MG
Waste activated sludge	- 700 lb/MG
Trickling filter	- 650 lb/MG
Filtration	- 125 lb/MG
Biological denitrification	- 130 lb/MG

From the above figures, if one adds primary and waste activated sludge a total of 1700 lbs/MG is derived. A typical rule of thumb for conventional activated sludge systems is sludge generation of between 1600 and 2000 lbs/MG. Note that the advanced waste treatment unit operations filtration and biological denitrification both contribute relatively low amounts of sludge.

The largest contributors of process residues from AWT unit operations are those associated with chemical coagulation and precipitation systems. Typical ranges of solids productions are[2]:

Lime (350-500 mg/l) to primary	- 2500 - 8000 lb/MG
Alum (13-22 mg/l) to primary	- 1200 - 1500 lb/MG
Iron (20-30 mg/l) to primary	- 1400 - 4500 lb/MG
Alum (9-20 mg/l) to secondary	- 700 - 1500 lb/MG
Iron (10-30 mg/l) to secondary	- 1100 - 2000 lb/MG
Lime (250-450 mg/l) after secondary	- 3000 - 7000 lb/MG

From the above values, one can observe that the addition of lime is the largest contributor to process residues. A typical rule of thumb is that the addition of alum to a secondary activated sludge plant will increase sludge production by up to 25%. One can normally expect about 4 pounds of sludge for about every pound of alum as aluminum added.

Of course, there are significant variations to this rule. Typically, a little more sludge is generated for iron than for alum. Also, the potential range of concentrations added is also broader. The amount of lime sludge is very difficult to predict because the generation of lime sludge is strongly influenced by the alkalinity of the feed water. Lime precipitation is a pH dependent phenomenon. For two-stage lime treatment, a pH of about 11.3 to 11.4 is required. The amount of lime necessary to reach these levels is of course dependent upon the characteristics of water. The lime process itself, can be considered a variation of the traditional softening process. Most of the lime added is precipitated as a calcium carbonate in a two-stage system. For this reason, most plants over a few MGD have been installing recalcination facilities. This is usually done to avoid a very large sludge disposal problem.

It should be noted that when alum, iron, or lime is added to a primary treatment system, significant amounts of organics are removed that would otherwise be going to the secondary plant. Thus, the organic loading in the activated sludge plants will be less, and therefore, less biological sludge will be produced.

From the foregoing discussion, it should be obvious that the type and amount of sludge that is produced can be influenced by the selection of the unit processes. There are obviously significant differences between iron and lime for phosphorus removal in terms of sludge generation. At the same time, there may be significant differences in terms of process performance. Therefore, a very careful analysis is required at the beginning of any design program to determine what level of treatment is truly required, particularly for phosphorus removal. If very high phosphorus removal levels are required, then one must almost have to use a two-stage lime system, therefore, deal with the large amounts of sludge generated. If lesser amounts of phosphorus removal are acceptable, say 80–90%, then it can be accomplished with the use of alum or iron salts with a corresponding lower amount of process residues produced.

Design of Unit Processes

The design of biological treatment systems can also exert an influence on the amount of sludge produced. Lightly loaded plants tend to go into endogenous respiration and can minimize somewhat, or reduce, the amount of sludge produced. More importantly, however, the volatile solids content of biological sludge can be inflluenced in this manner. The inclusion or exclusion of industrial wastes can strongly influence the characteristics and amounts of process residues. One can control the quality of industrial contributions to sewer systems by adequate ordinances or pretreatment regulations. Of course, effective enforcement must be provided. As is well known, the chemicals in industrial waste can effect the quality and characteristics of waste biological sludges to a significant degree. As mentioned previously, biological sludges tend to adsorb metals. Individual organic compounds have different degradation and sludge production rates. Thus influencing the overall average rates that are exhibited by a biological system. Some organic materials are inhibitory in nature and might slow down the biological processes. This might require higher loading rate or a different set of design parameters than would otherwise be the case. If significant amounts of industrial waste are present in any sewage, then it is imperative to completely characterize the sludge production characteristics of the resultant sewage prior to the development or design of sludge handling and disposal facilities. Traditional rules of thumb cannot be relied upon in these instances to provide accurate information so that effective systems can be devised.

There are several other factors in the design of unit processes that affect sludge characteristics: choice of precipitant or coagulant; location of chemical addition; design of clarifiers; and recovery of chemicals are some major means of influencing sludge production in the design phase. The location of chemical addition, as well as the location of the end point of recycle streams, can be an important factor in determining how much of chemical sludges will be produced as well as what unit operation will ultimately deal with this waste material. For example, if chemical addition is practiced in the primary system, less biological sludge can be expected in the secondary plant, as has been previously mentioned. Clarifiers can be designed to provide optimum sludge compaction within the limits of efficient clarifier operation. This could reduce the dewatering load on subsequent downstream sludge handling operations. As mentioned previously, lime has been successfully recovered in a large number of installations that are operating on waste lime sludge from tertiary unit operations. This is accepted technology and there is no doubt that lime can be successfully recovered. Alum has been recovered on a pilot plant basis in physical chemical treatment plants. This has not, as yet, been reduced to practice on a large plant scale.

Operating Mode

Finally, the particular method of operation can significantly influence sludge production and characteristics. For example, close control of chemical dose rates is required to minimize the amount of chemical sludge that might be produced. This is particularly true with iron and alum systems; as excess iron and alum are fed beyond that which is required for phosphorus removal, more sludge is simply produced. This is somewhat of an over simplification; a point will be reached where more sludge is not created with increasing chemical dose but this is not usually reached within the variation of waste treatment plants. Sludge removal rates from clarifiers can also influence the septicity and to a large degree the percent of solids in the sludge removed. Also, as stated previously, the biological loading at which one operates the plant can to some degree influence the amount of sludge produced. However, it is very difficult to quantify the benefits derived from a particular set of loadings at a given plant in terms of sludge production mainly because of the constantly changing nature of the raw waste.

SUMMARY

In summary, the major method of controlling the amount and quality and characteristics of process residues appear to be in the selection and design of unit operations. Thus, it is imperative that sludge production be considered very early in the design phase. In the past, sludge production has usually been overlooked in the initial process design, and has been considered only after the main process streams have been derived. Because of new regulations on treatment plant performance, new types of unit operations have been developed and are being put into use. These require the designer to reconsider assumptions of the past that may be valid for treatment conditions that are no longer applicable. Thus, the process residue generation characteristics of all unit operators considered must be evaluated very early in the process design stage so that sludge production along with related handling and treatment facilities can be optimized.

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Economics of Transport Methods of Sludge

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INTRODUCTION

One significant effect of increasingly stringent discharge standards is that the treatment facility must process a larger volume of solids. This, coupled with increased restrictions in disposal of solids and, in some cases, a greater value placed on the solids themselves has changed solids handling unit processes significantly. It is becoming increasingly common to transport solids in liquid or dewatered form from one location to another as part of the treatment, disposal, or reuse steps. Significant technical and cost considerations must be evaluated in planning a transport system to achieve satisfactory results. The costs associated with transport can be very substantial.

This paper will discuss general aspects of solids transportation systems by truck, barge, railroad, and pipeline.

A significant EPA sponsored sewage sludge transport cost study was completed by Culp/Wesner/Culp, Clean Water Consultants. The purpose of this study was to develop a method of calculating transport costs for each mode using basic parameters such as gallons of fuel, operator manhours, operating miles, and similar factors. Therefore, the information developed in the study would not grow out of date with inflation and current unit costs could be used in making calculations at any future date. Formats are set up in the study for both manual and computer calculation of transport costs and methods of escalation. This paper represents a very general summary of the information in the EPA study. Time and space do not permit a presentation of the total calculation procedure nor complete breakdown of cost estimates, so only total cost information is provided herein. A copy of the EPA study, Contract No. 68-03-2186, should be obtained if greater detail is needed.

The purpose of this paper is to discuss some general considerations for each transport mode and to present the general cost information. The information herein should be helpful to anyone studying sludge transport but each situation should be studied in detail before final decisions are made. The information in this paper is not intended to provide detailed information.

FORMAT

In this paper the transport system is considered as a unit process. The total costs for the transport unit process consist of:

1. Point to point transport costs including capital and O & M.
2. Facilities capital and O & M costs. (in case of truck, barge, and railroad).

The facility costs are broken out separately because they are variable depending on climate, designer, type of plant and other factors. The facilities and the associated capital and O & M costs used in developing cost curves are shown in Tables I and II. Generally, facilities consist of loading and unloading equipment and structures.

Table I: Transport Facilities

	Transport Mode		
	Truck	Railroad	Barge
Liquid			
Loading Storage	No(2)	Yes	Yes
Loading Equipment	Yes	Yes	Yes
Dispatch Office	Yes	Yes	Yes
Dock and Control Bldg.	N/A	N/A	Yes
Railroad Siding(s)	N/A	Yes	N/A
Unloading Equipment	Yes	Yes	Yes
Unloading Storage(1)	No	No	No
Dewatered			
Loading Storage	Yes(3)	Yes	N/A
Loading Equipment	Yes	Yes	N/A
Dispatch Office	Yes	Yes	N/A
Dock and Control Bldg.	N/A	N/A	N/A
Railroad Siding(s)	N/A	Yes	N/A
Unloading Equipment	Yes	Yes	N/A
Unloading Storage(1)	No	No	N/A

(1) Storage assumed to be a part of another unit process
(2) Storage required for one or two truckloads is small compared with normal plant sludge storage.
(3) Elevated storage for ease of gravity transfer to trucks.

Pipeline facilities consist of pipeline and pumping stations.

Forms of Sludges Considered

The forms of sludge studied and the transport modes are

	Form of Sludge	
Transport Mode	Liquid	Dewatered
Truck	X	X
Barge	X	
Railroad	X	X
Pipeline	X	

The most common liquid sludge concentration is 1 to 4 percent solids although liquid sludge up to 10 percent solids can be handled with relative ease. Dewatered sludges are normally 15 to 50 percent solids and can be moved with belt conveyors or similar handling systems. All cost information is based on gallons and cubic yards so sludge form and total volume are the pertinent units.

Table II: Facilities Capital and O & M Costs

Transport Mode & Volume	Facilities Capital, $1000		Facilities O & M, $1000/yr.	
	Liquid	Dewatered	Liquid	Dewatered
Truck (1)(2)				
1.5	38	50	10	10
5	40	50	15	15
15	64	50	20	20
50	104	80	30	30
150	150	105	39	39
Barge (1)				
7.5	400	--	17	--
15	400	--	18	--
75	646	--	42	--
150	646	--	52	--
750	899	--	144	--
Railroad (1)(2)				
7.5	180	145	37	19
15	202	145	40	33
75	382	149	83	42
150	563	253	103	51
750	1,156	610	277	131
Pipeline -	No facilities other than pipeline and pumping stations.			

(1) Millions of gallons of sludge per year for liquid
(2) Thousands of cubic yards of sludge per year for dewatered

The solids content of each form of sludge can vary over a range without significantly changing the actual transport cost per given volume.

Therefore, it is recommended that initial cost calculations be based on the units pertinent to method of the haul.

The costs can be converted to other units, such as dollars per dry ton mile, after the total costs for a case have been determined.

Truck Transport

Truck is widely used for transport of both liquid and dewatered sludges. This mode offers flexibility because the terminal points and route of haul can be changed readily and at low cost. Investment in terminal facilities can be minimal. Many truck configurations are available ranging from standard tank and dump bodies to very specialized equipment for hauling and spreading sludges. Trucks can be purchased or leased or the hauling contracted to a private operator. The generalized cost curves were based on the following criteria and assumptions:

1. Most economical type truck from selection of standard frame or semi-trailer mounted bodies; tanks for liquid and dump or ram type for dewatered.
2. Eight hours of trucking operation per day.
3. Fuel cost at $0.60 per gallon.
4. Operating and maintenance labor at $8.00 per hour including fringes.
5. Electric energy at $0.02 per kwh.
6. Amortization of truck capital cost over 6 years at 7 percent.
7. Truck O & M cost, excluding fuel and operator, $0.20 to 0.30 per mile depending on type of truck.
8. Truck loading time 30 minutes and unloading time 15 minutes.
9. Truck average speed 25 mph for first 20 miles one way and 35 mph for rest.
10. General and administrative costs 25 percent of total O & M cost.

In general, the total cost of truck transport will be decreased (per unit of material hauled) if the daily period of truck operation is increased. Restrictions may be placed on any significant truck operations such as specific routes or daylight hours for operations. The larger trucks are the most economical except for one way haul distances less than ten miles and annual sludge volumes less than 3,000 cubic yards for dewatered sludge and for less than one million gallons per year for liquid sludge. Generally, diesel engines are used in the larger trucks and are the economical choice for small trucks when operated at high annual mileage. Truck manufacturers and dealers can provide exact information for their particular equipment.

Barge Transport

Barge transport has been used in the past for ocean disposal of sludges, but barge can be used for transport of sludges between land points that are connected by navigable waterways. The use of barges is limited to those locations in reasonable proximity to suitable waterways.

Barges have been used in the past for transport of liquid sludges and no applications for dewatered sludges are known. Barges can be leased or purchased or the barging can be performed by an outside private operator. In most cases, the towing is subcontracted to a tug operator. Self propelled barges have been used in New York City for many years but, except for special cases, separate tugs and barges offer more flexibility.

In general, the large barges are much more cost effective than smaller barges. Larger barges have deeper drafts and, therefore, may not be practical for many inland waterways. The major factor in barging is the cost of tug (towing) services and the larger barges minimize this cost.

The information in this paper is based on barges up to 850,000 gallon capacity, but barges are available in sizes to two million gallons and greater. These larger sizes will substantially reduce the cost of transport for medium to large installations, but the larger barges may be too large for some inland waterways. As an example, for an annual sludge volume of 150 million gallons and a one way haul distance of 150 miles, the total annual cost using two million gallon capacity barges was half of the total annual cost using 850,000 gallon barges.

The generalized cost curves were based on the following criteria and assumptions:

1. Most economical barge size up to 850,000 gallons.
2. Single barge per tow.
3. Towing services contracted to outside tug operator.
4. Operating and maintenance labor at $8.00 per hour including fringes.
5. Electric energy at $0.02 per kwh.
6. Amortization of barge cost over twenty years at 7 percent.
7. Barge loading and unloading time five hours each.
8. Barge average towing speed 4 mph.
9. Barges not manned during tow.
10. General and administrative costs 25% of total O & M cost.

Barge transit times will be variable depending on traffic, draw bridges, locks, tides, currents, and other factors. The 4 mph speed is an average and speeds in open water may exceed 7 mph. Barges are normally unmanned during transit.

Loading can be accomplished by either a gravity pipeline or pump(s) and pipeline from a storage tank. A barge is normally filled in 2-5 hrs.

Unloading requires a pump(s) and for transfer of sludge to a storage system. The pump can be barge or dock mounted and can be diesel or electric.

The use of barge was limited in this paper to liquid sludge because of the difficulty of unloading dewatered sludge from a barge and because of lack of full scale experience.

Railroad Transport

It is hard to obtain information on railroad transport for generalized cases. Most rail companies prefer to deal in specific cases. Policies vary throughout the country, but general comments are pertinent to most cases. There are very few actual cases of rail transport of sludges at present, so there is little past experience from which to draw information.

Rail companies will provide cars if they are available, but in most cases tank cars are not available. Most rail companies also indicated that suitable cars for dewatered sludge would not normally be available in any quantity nor on a regular basis. Rail cars can be leased from manufacturers such as GATX on a full maintenance basis. This would be the best method to assure a continuous supply of cars in good running condition. Rail companies provide a rebate of approximately $0.06 to $0.20 per loaded mile (depending on condition of the car) to compensate the shipper for providing his own cars. The number of cars required is related to the round trip transit time and this time can be significant. Transit times may be reduced in special cases and with careful planning. This will have a significant effect on the number of rail cars needed and, hence, on capital or lease costs. Even with careful planning it would be difficult to reduce rail transit time, even between close points, to less than three days round trip because of train make-up, switching, and weighing. Round trip transit time typically will be four to eight days for one way haul distances of 20 to 320 miles.

Rail rates vary widely, but in general, rates in various parts of the country vary according to the following table:

Area	Approximate Railroad Rate Variation
North Central and Central	Average
Northeast	25% Higher than Average
Southeast	25% Lower than Average
Southwest	10% Lower than Average
West Coast	10% Higher than Average

Great difficulty was experienced in obtaining typical rates from the rail companies. The following rates were used in preparing the cost curves herein.

One Way Distance, Miles	Rate, $/Net Ton
20	2.10
40	3.00
80	4.10
160	6.50
320	12.20

Pipeline Transport

There are many choices to be made in the design of a sludge pipeline system. The following assumptions were made for purposes of this study and are representative of design criteria used in actual designs. The liquid sludge was assumed to be reasonably free of grit and grease, similar to anaerobically digested material.

Raw sludge can also be transported by pipeline, but the grease may require additional maintenance procedures. The solids content does not affect the calculations within the range of 0–4 percent solids. The minimum pipeline size is 4 inch. The literature describes installations with smaller pipelines, but these small pipelines represent special design cases.

Sludge pumps are of the dry pit, horizontal or vertical, non-clog, centrifugal type operating at 1,780 rpm. Lower speed pumps are available and might be selected for specific projects depending on the conditions. The non-clog centrifugal pumps are relatively inefficient for low flows, but approach 80% efficiency at optimum conditions. They are widely used for sludge pumping applications. Other types of pumps are used, but this study did not attempt to optimize the pumping for each pipeline size. The assumed pump characteristics are based on manufacturers' published data. Because of the high friction loss in the 4 and 6 inch pipelines, the corresponding pumping stations for these lines contain more than one pump in series in order to develop higher pumping heads and minimize the number of stations. Two pumps are operated in parallel for the 16, 18, and 20 inch pipelines because of the high flows. Each pumping station contains facilities for pipeline cleaning using plastic pigs and macerators to assure a controlled maximum particle size in the pumped sludge. Operating experience from existing installations indicates that special conditioning of liquid sludge is not required prior to transport by pipeline except for macerators which are used in some installations. Most pipelines do have facilities for routine cleaning and plastic pigs seem to be the most common method. Pig insertion and retrieval facilities are included in the pumping stations and the O & M costs include those associated with the use of pigs.

The pipeline is based on use of cement lined cast iron or ductile iron pipe which is typical for sludge pipelines. The cement lining provides long life and a smooth interior surface. A "C" factor of 90 is used for purposes of hydraulic calculations. Installation is assumed to be in normal soil conditions with average shoring and water problems typical to shallow force main installations. Installation is assumed to be above hard rock. The pipeline cost included one major highway crossing per mile and one single track railroad crossing per five miles plus a number of driveway and several minor road crossings per mile. These costs should be typical for average installations to be expected for sludge pipelines. The pipeline costs were developed from recent ENR bid breakdowns and other current information.

The literature indicates that sludge pipeline velocity can range from about 2.5 to 8 feet per second (fps) for satisfactory operation, but a velocity of 2.5 to 3.0 fps is used by a number of consultants in pipeline design. The pipelines in this study were designed based on an operating velocity of 3 fps.

The depth of the pipeline will not affect the capital cost within the range of 3 to 6 feet of burial in normal soil. Most sludge pipeline installations will be within this depth range.

Sludge pumping station costs were determined from published cost studies and from actual and proposed sludge pumping stations.

The O & M labor and O & M supplies will vary to a degree with the number of hours of operation per day, but the difference in the total costs is insignificant so these factors were considered constant for a given size pipeline.

Proper design of sludge pipelines should provide nearly 100 percent availability and, therefore, auxiliary sludge storage volume is not provided in this study. Normal plant sludge storage should be adequate.

Facilities at the discharge end of the pipeline such as lagoons, dewatering equipment, or spreading equipment are assumed to be a part of other unit processes.

Pipeline transport was based on agency ownership and operation of all portions of the system. Electrical energy and labor cost assumptions are the same as for the other transport modes.

Cost information for the pipeline mode is based on pipeline size. The relationship between pipeline size and sludge volume is shown in Table III.

Facilities

Facilities cost estimates in Table II were based on the amortization, operation, and maintenance of the facilities shown in Table I for each transport mode. The costs were based on published EPA cost studies, primarily the Black and Veatch study, and on estimates made from information contained in published cost estimating guides. Facilities will be variable and those outlined in Table I were used only as typical examples.

RESULTS AND CONCLUSIONS

General cost information for each transport mode is shown in Figures 1 through 11. Figures 1, 3, 4, 7, and 9 show only the point to point transport costs (no facilities) and Figures 2, 4, 6, 8, 10, and 11 show total costs including facilities and facilities O & M. This information should only be used for general cost determination because the costs and relative costs will vary by geographical location and situation. The following general observations can be developed from the information in Figures 1 through 11 and other information contained herein.

1. Dewatered Sludge.

   Total annual cost for railroad is less than truck for all annual sludge volumes and distances studied herein with and without facilities.

Table III: Pipeline Transport—Pipeline Size, Sludge Flow & Sludge Volume

Pipeline Size, Inches	Sludge Flow Rate, GPM @ ≅ 3 fps velocity	Pipeline Capacity at 3 FPS Velocity For Various Daily Operating Periods, MGD			
		4 HRS	8 HRS	12 HRS	20 HRS
4	120	0.03	0.06	0.09	0.14
6	280	-	0.13	0.20	0.34
8	500	-	0.24	0.36	0.60
10	800	-	0.38	0.58	0.96
12	1,100	-	0.53	0.79	1.32
14	1,400	-	0.67	1.01	1.68
16	2,000	-	0.96	1.44	2.40
18	2,500	-	1.20	1.80	3.00
20	3,000	-	1.44	2.16	3.60

- Railroad facilities are more capital intensive than truck facilities.
- Transport equipment can be leased in both cases.

2. Liquid Sludge.
   - Truck is the least expensive mode for one way distances of 20 miles or less and sludge volumes less than 10 to 15 million gallons per year.
   - Pipeline is the least expensive mode for all cases when the annual sludge volume is greater than approximately 30–70 million gallons (depending on distance).
   - Pipeline is not economically attractive for annual sludge volumes of 10 million gallons or less because of the high capital investment.
   - Pipeline is capital intensive and the terminal points are not easily changed. Pipeline is ideal for large volumes of sludge transported between two fixed points.
   - Rail and barge are comparable over the 7 to 700 million gallon volume range for long haul distances.
   - Barge is more economical than rail for short to medium distances for annual sludge volumes greater than 30 million gallons.

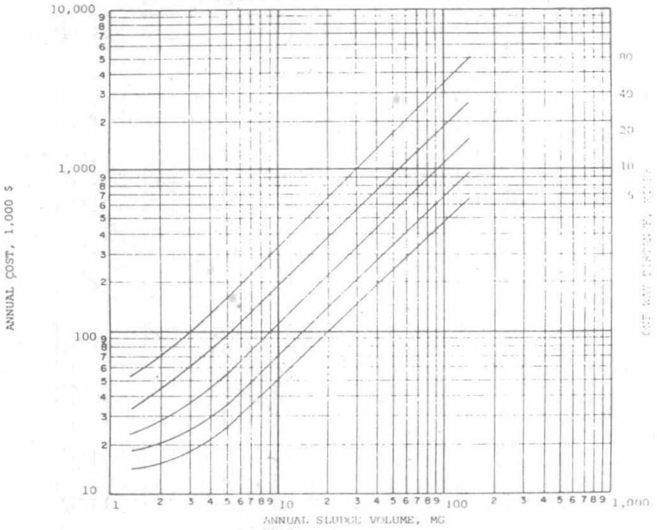

Figure 1: Truck Transport Total Annual Cost Without Facilities 8 Hour Operation Per Day Liquid Sludge (1976)

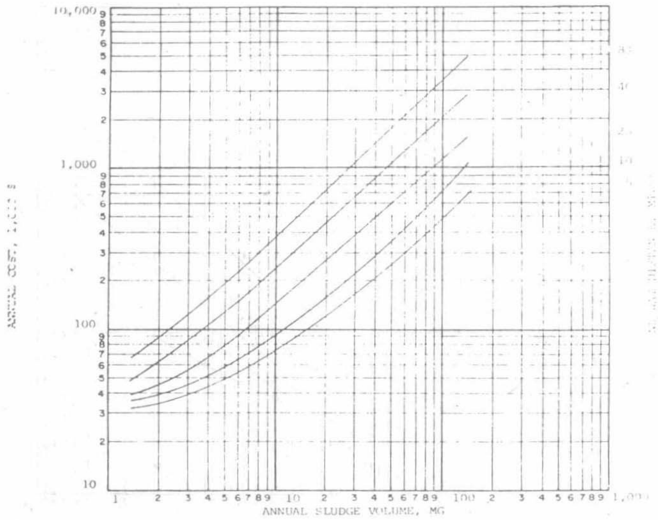

Figure 2: Truck Transport Total Annual Cost With Loading & Unloading Facilities 8 Hour Operation Per Day Liquid Sludge (1976)

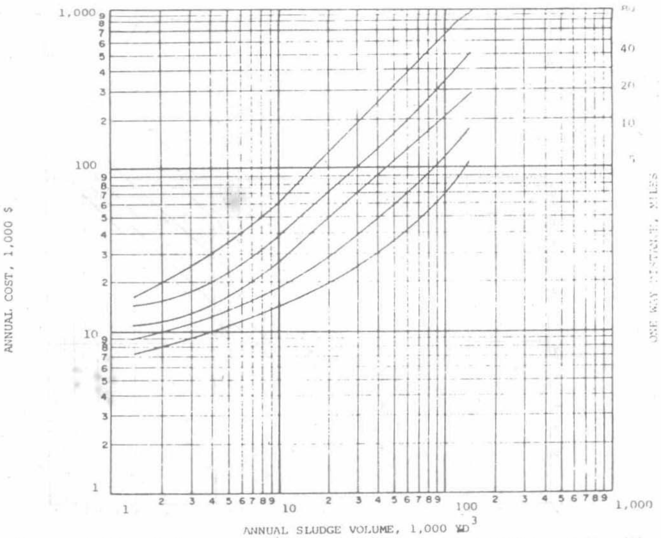

Figure 3: Truck Transport Total Annual Cost Without Facilities 8 Hour Operation Per Day Dewatered Sludge (1976)

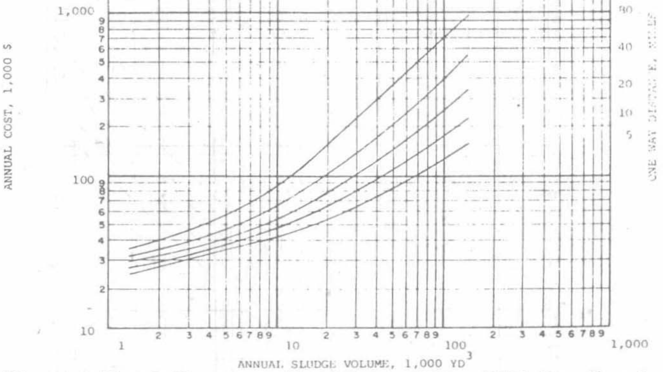

Figure 4: Truck Transport Total Annual Cost With Loading & Unloading Facilities 8 Hour Operation Per Day Dewatered Sludge (1976)

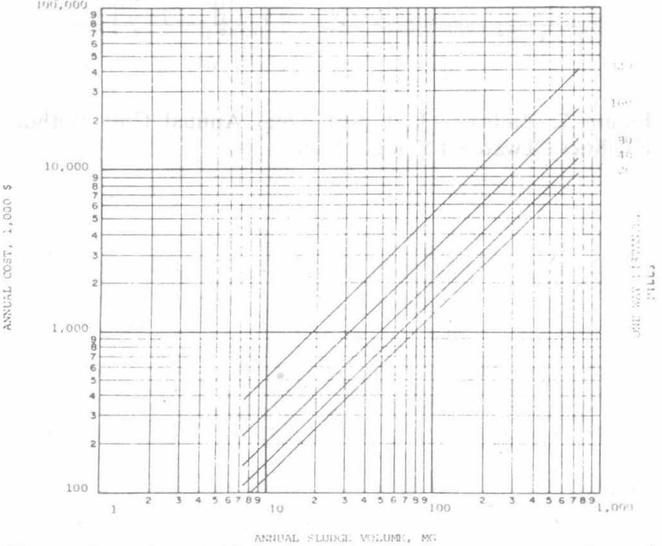

Figure 5: Railroad Transport Total Annual Cost Without Facilities Liquid Sludge (1976)